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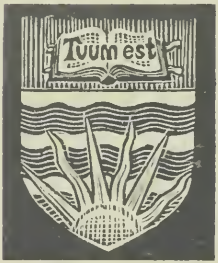

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LECTURE EXPERIMENTS IN OPTICS

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BY

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WITH A FOREWORD BY

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PREFACE

This handbook is intended to serve as a convenient reference for the setting up of a number of lecture experiments in optics. No attempt is made at a lengthy description of the theory of any particular experiment, but rather are these pages intended to help the lecturer to explain the theory by means of practical demonstration. Whilst realizing that the number of experiments included in the book is quite inadequate, an attempt has been made to bring together some of the more fundamental ones in optics. For this reason some of the experiments may appear of a very elementary nature, but they are no less important on this account. A feature of the descriptions given is the detailed tabulation at the end of each experiment of all the apparatus required, so that the assistant may run through these prior to the lecture to see that everything is present—for how often has a good experiment been completely spoiled due to the omission of a minor part of the apparatus! A large number of diagrams have been purposely introduced into the book, so as to enable the arrangement of any experiment to be more readily understood without the necessity of lengthy explanations; some of the diagrams may be helpful in suggesting ideas for drawings from which lantern slides could be made. I am indebted indirectly to Professor F. J. Cheshire for knowledge in the matter of setting up good experiments, obtained whilst working with him

several years ago. Also I wish to express my thanks to Professor L. C. Martin for his kindness in writing the Foreword. It is hoped that the book may be of help to those who have to teach optics in any of its forms.

B. K. JOHNSON.

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FOREWORD

The preparation of an effective experimental accompaniment to lectures on Optics is by no means an easy matter, but there are few subjects in which effective experiments yield a better reward. Mr. Johnson has had most valuable experience in this connection, being for several years associated with Professor Cheshire, who belonged to that great school of experimental lecturers in which Tyndall was perhaps the greatest figure. The Technical Optics Department of the Imperial College has striven to maintain this tradition, in spite of all difficulties, although post-graduate experimental work must mainly leave the broad effects of the lecture table for the refined observations of the laboratory bench. Mr. Johnson's ingenuity and technical resource are reflected in the pages of this book, and those who are anxious to make fullest use of the possibilities of optical experiments will do well to study its pages and adopt some at least of the methods and apparatus therein described.

Experience has shown that the standardization of apparatus and fittings for experimental demonstration results in a great saving of time and worry; it is therefore worthy of determined effort and the necessary expense.

L. C. MARTIN.

LECTURE EXPERIMENTS IN OPTICS

I

DESCRIPTION OF PROJECTION APPARATUS

In order to carry out many of the following lecture experiments to their best advantage it is desirable to have a means whereby the apparatus is suitably raised above the lecture table, so that all members of the class may have an opportunity of seeing clearly both the way in which the experiment is performed and the final result projected on the screen at the side of the theatre.

With this aim in view, the device shown in Fig. 1 was developed and has proved entirely satisfactory. It consists of a wooden framework 12 in. high on which is mounted a triangular bar—1 metre long—and a housing for the source of light. The former carries the saddles, which hold any desired fitting, and thus ensures correct alignment of the optical parts, whilst the latter is very necessary for preventing stray light from the high-power source from going out into the lecture room. The source of light itself may consist either of an electric carbon arc (taking 5 to 10 amperes) or a tungsten arc in the form of a 500 c.p. "Pointolite" lamp; the first named is usually employed chiefly on account of it having a greater intrinsic brightness than the "Pointolite" and also because it is

less expensive. Nevertheless, the great advantage of *steadiness* of the source should not be overlooked, and from this point of view the "Pointolite" is distinctly superior to the arc; moreover, the 500 c.p. type is sufficiently bright for the majority of experiments. A

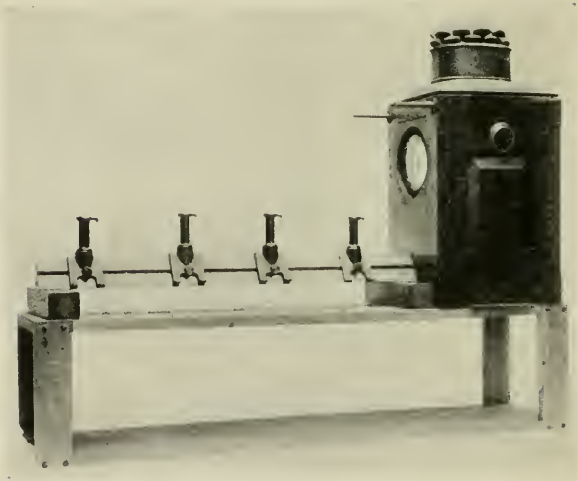


Fig. 1.—Arrangement of Projection Apparatus.

lantern condenser is fitted into the front of the housing and provision should be made for moving the light source backwards or forwards so that beams of different vergence may be used at will.

Mention must be made also of the various fittings for the saddles, and which are necessary for a suitable range

of experiments; the minimum number is stated and the list is intended to give some idea of the requirements in the event of such equipment being purchased; they are shown in Fig. 2:—

(A) Circular apertures of different diameters mounted on one fitting.

(B) Mount with clip—rotating about horizontal axis.

(C) Slit—adjustable jaws—rotatable about a horizontal axis.

(D) Small wooden table—for prisms, etc.

(E) Projecting lens fitted with screen for cutting off extraneous light. Five of these of the following focal lengths will be found a convenient series to draw upon: 18 in focus, 13 in. f., 8 in. f., 4 in. f., and 2 in. f.—lenses from a trial case mounted in this way will serve perfectly well, their respective dioptric values being 2·25 D., 3·0 D., 5·0 D., 10 D.; whilst for the 2 in. focus lens it will be found better to purchase a properly corrected lens system, such as a cinematograph projection lens.

(F) Lantern slide holder. Desirable types of objects (made in metal in order to withstand heat) for fitting into grooves of holder F are shown in Fig. 3.

(G) "V" support—for holding tubes.

(H) Clips—one or two stout paper clips mounted on metal stems.

(I) Iris diaphragm—closing down to $\frac{1}{8}$ in. in diameter.

(J) Hollow 60° prism filled with carbon disulphide.

(K) Holder for unmounted lenses.

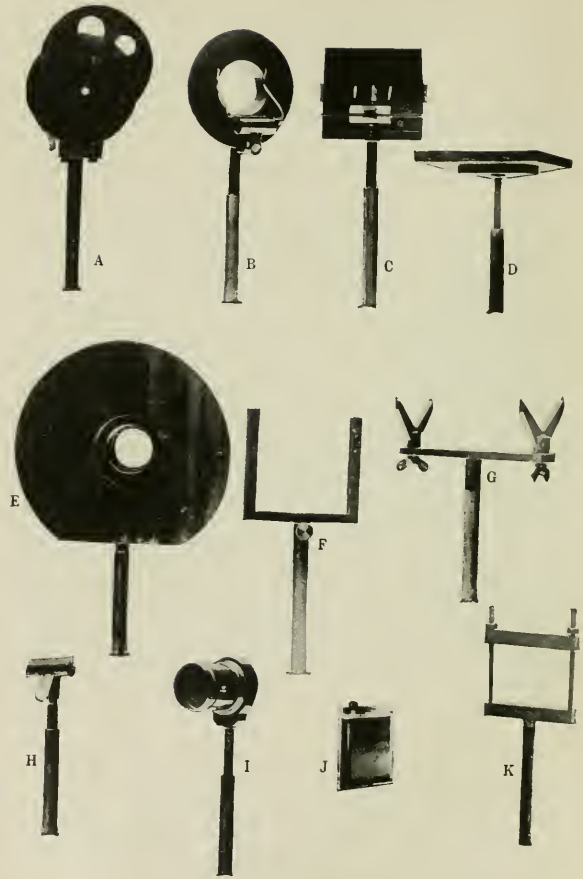


Fig. 2.—Optical Bench Fittings.

These fittings can, of course, be added to as circumstances arise, as is in fact suggested in certain experiments later in the book. The setting up of experiments is

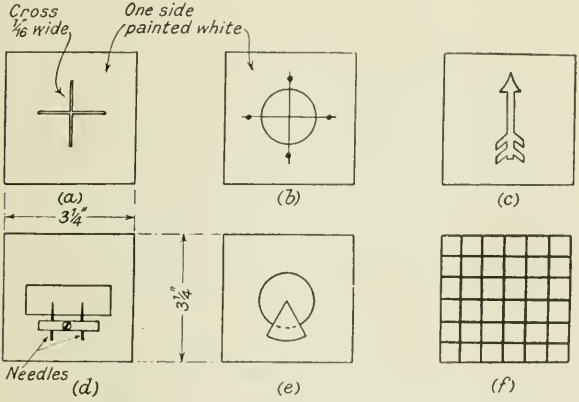


Fig. 3.—Types of Object for fitting into Lantern Slide Holder, F, Fig. 2.

greatly facilitated if all the fittings are made to a standard height to the optical centre (say 7 in.).

The possession of such apparatus as briefly described will be found of considerable value to the lecturer.

Any of the apparatus shown in Figs. 1 and 2 may be obtained from The Precision Tool Co., 72 Newington Butts, London, S.E.

II

RECTILINEAR PROPAGATION OF LIGHT

(*a*) "Pinhole Camera."

One of the best illustrations of this is afforded by the so-called "pinhole camera" (invented by Porta in the sixteenth century), but to demonstrate the latter to a class is not always an easy matter. The following method has proved effective—see Fig. 4. The object O consists of an irregular-shaped filament, as fitted in some of the

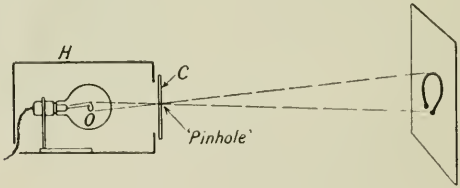


Fig. 4.—Illustrating "Pinhole Camera" Experiment.

modern gas-filled electric lamps (a horse-shoe shape is convenient). This lamp (which should not be less than 100-watt) must be well screened in a suitable housing H. If now a piece of thin card or tinfoil with a hole pierced by a stout pin (say 2 mm. diam.) is placed at C, an inverted image of the filament will be seen on the screen some 15 ft. away. Further, it is of interest to prick several holes in the card or foil and observe the corresponding number of images; also the loss in definition of the image

may be shown by enlarging one of the holes to approximately 6 mm. in diameter.

Perhaps a more striking method is to hold a bunch of leaves in place of the card C, when numbers of images of the filament will be seen on the screen formed by

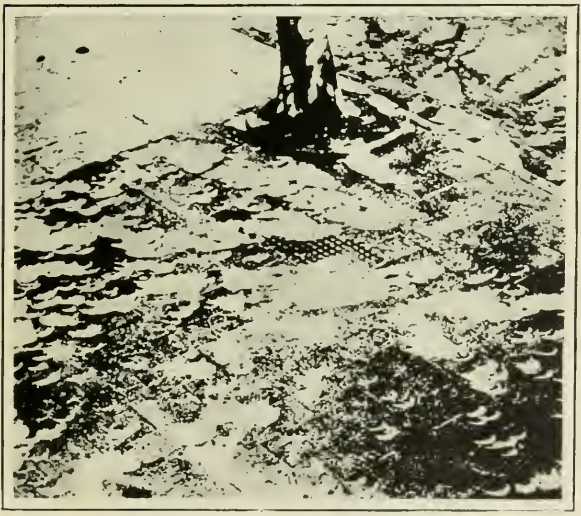


Fig. 5.—View of Pavement during an Eclipse, showing Crescent Images formed by "Pinholes" produced by Foliage of the Tree.

the small apertures produced by the inter-crossing of the foliage. As an example of this, the crescent-shaped images of the sun seen beneath trees during an eclipse may be quoted—a photograph of this appearance is shown in Fig. 5.

Fig. 6.—The Royal College of Science, South Kensington, taken with a "Pinhole" Camera.

Fig. 6 is a photograph taken with a pinhole camera, the details of which are: diameter of drilled hole = ·35 mm., distance of plate from hole = 8 cms., angle subtended by extremities of the building = 78°. Exposure = 7 minutes.

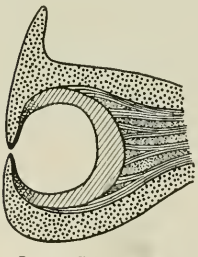


Fig. 7.—Eye of Nautilus.

It is instructive to pass round the class a postal tube having at one end a piece of tinfoil with a hole in it and at the other a piece of ground-glass screen, so that by having the room in darkness students may observe the inverted image of an object (e.g. a lighted candle) standing on the lecture table.

Fig. 7 is a sectional diagram of the eye of the Nautilus and shows how Nature has employed the "pinhole" for the production of a retinal image.

Apparatus:—As described.

(*b*) Shadows.

In dealing with the subject of shadow cones and their relation to solar and lunar eclipses, it is desirable to illus-

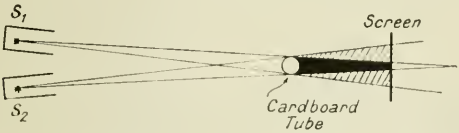


Fig. 8.—Experiment Illustrating Shadow Cones.

trate in a practical way what is meant by the umbral and penumbral shadows. This may be done by placing two point sources, such as naked arc lamps, side by side on the lecture table and holding a cardboard tube of say 6 in. diameter in the path of the beams some 3 ft. away from the screen, when both the umbra and penumbra will be clearly seen—see Fig. 8.

Apparatus:—2 small arc lamps *without* condensers (enclosed at sides and back). Cardboard tube (say, 3 in. to 6 in. diam.).

III

REFLECTION AND REFRACTION

Reflection

(*a*) Laws of Reflection.

The following experiment for demonstrating the laws of reflection seems to have received general appreciation:—

On a large sheet of paper or canvas should be boldly drawn a semi-circle (2 ft. radius) marked out in angular divisions of 10 degrees. This can be pinned down to

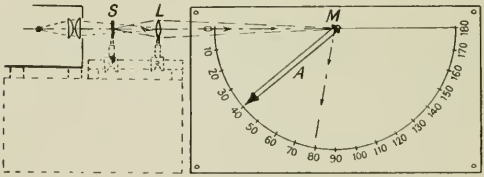


Fig. 9.—Laws of Reflection.

a board and supported in a vertical position or in a horizontal plane if the lecture room has seats raised towards the back; over the centre of the semi-circle is pivoted an arm A (Fig. 9) which carries a strip of mirror glass 1 in. wide by 4 in. high with its face normal to A and mounted over the centre of rotation. Light from the source is brought to a focus on the lens L ; this lens (4 in. focus) forms an image of the slit S ($\frac{1}{8}$ in. wide) on the surface

of the mirror M, and if the latter is slightly inclined forwards the reflected "strip" of light will be visible on the semi-circular scale. The axis of the projector is made to coincide with the zero line of the scale, so that by rotating A into various positions it can be shown—by reading off the scale—that the angles of incidence and reflection are equal, and further that the reflected beam moves through twice the angle moved by the mirror.

Apparatus:—As described (special).
Room:—Illuminated.

(*b*) To show that the Image of an Object is situated at the same distance behind the Mirror as the Object is in front.

For this purpose a piece of thin sheet glass 18 in. square should be held in a vertical position and immediately in front of it is placed a lighted candle some 12 in. away. Whilst the class observe, the lecturer holding a second unlighted candle (similar in size) behind the glass (see Fig. 10) can adjust its position so that the observers see the image of the flame of the front candle apparently to coincide with the wick of the rear candle, thus producing the effect of the latter being really alight. After this has been observed,

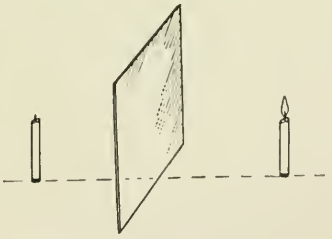


Fig. 10.—Position of Image by Reflection.

the distances from the candles to the glass can be measured, when they will be found the same and, further, the line joining the candles will be found perpendicular to the glass reflector.

Apparatus:—Piece of glass 18 in. square—2 candles—box of matches.
Room:—Semi-dark.

(*c*) Multiple Images by Reflection.

For illustrating multiple images the piece of apparatus known as the "book mirrors" will be found convenient; this consists, as its name implies, of two pieces of silvered mirror (18 in. square) joined together at one edge by a hinge. They can be stood on edge facing the class and opened at any desired angle, whilst a rod standing between them will enable the various images to be seen clearly (see Fig. 11). The most instructive angles are perhaps 90°, 60°, 45°, when the number of images will be 3, 5, and 7 respectively.

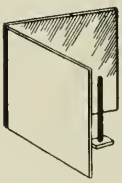


Fig. 11.—Multiple Reflection with Book Mirrors.

By sticking two small pieces of mirror glass on to a baseboard at such angles as named and mounting them over the centre of rotation M (of Fig. 9) it can be shown that the total deviation of the incident beam is equal to twice the exterior angle between the mirrors. By using the mirrors at 45°, the principle of the "pentagonal prism" may be demonstrated.

Apparatus:—"Book mirrors"—white rod on small baseboard.
Room:—Illuminated.

Refraction

(*d*) Coin in Trough Experiment.

A simple and perhaps striking experiment to an elementary class showing the phenomenon of refraction, can be performed by placing down on the floor in front of the students an empty earthenware trough in which is placed a flat circular piece of lead $2\frac{1}{2}$ in. diameter (representing a coin), the latter being just hidden from view to the class by the raised edge of the trough. If now water is poured into the trough the "coin" will gradually become visible (see Fig. 12). This experiment is most effectively carried out when the lecture theatre is one in which the seats are raised in tiers towards the back, as then the line of vision for each student is approximately the same.

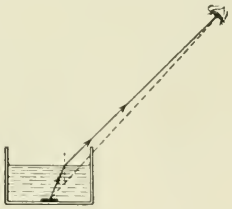


Fig. 12.—Coin in Trough Experiment.

Apparatus:—Trough—"coin"—jug of water.
Room:—Illuminated.

(*e*) Laws of Refraction.

For this and other refraction experiments, a glass tank 18 in. square (in side elevation) by 2 in. wide is valuable. Such a tank filled with water into which has been sprinkled a little fluorescein, enables the path of a refracted beam of light to be clearly seen in the water. It is an advantage to have the tank raised on legs as then the direction of the light may be seen after passing out of the denser medium.

To prove the second law of refraction experimentally, a piece of white card on which is clearly drawn a circle with angular divisions may be placed behind the tank as indicated in Fig. 13. A narrow beam of light is then sent towards the water surface at G at any chosen angle with the normal NG and its corresponding refracted angle is read off, by observing its passage in the water, made visible by the particles of fluorescein held in suspension,

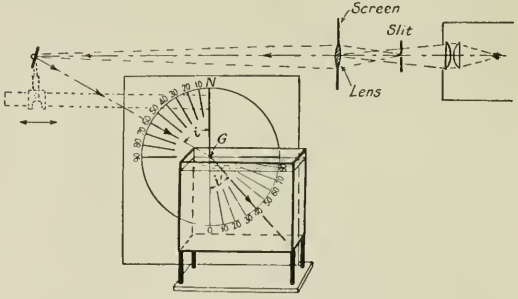


Fig. 13.—Laws of Refraction.

If this is done for two or more different incidence angles and the sines of these and their corresponding refracted angles taken, it can be shown that $\frac{\sin i}{\sin i'} = \text{constant} = \frac{n'}{n}$ (where n is the refractive index of the first medium and n' that of the second).

Apparatus:—Optical bench and projection lantern—3 saddles.
O.B. Fittings:—Horizontal slit (Fig. 2, C).
4 in. focus projection lens (Fig. 2, E).
Rotatable mirror.
Special glass tank—water—fluorescein—white card with angular divisions.
Room:—Semi-dark.

(*f*) Critical Angle and Internal Reflection.

This may be shown by employing the above-mentioned tank as shown in Fig. 14. A parallel beam of light, produced by the lens L and horizontal slit S, is made to enter the water tank by reflection from the mirror M. By rotating the latter, the beam may first be made to emerge from the upper surface of the water, then the "critical angle" is reached, and finally total internal reflection shown. It will be found better to employ a monochromatic filter (green) in front of the slit as this prevents troublesome dispersion effects.

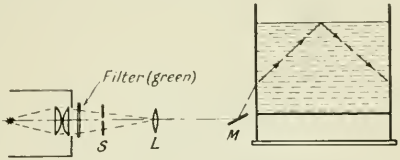


Fig. 14.—Critical Angle and Internal Reflection.

Apparatus:—Optical bench and projection lantern—3 saddles.
O.B. Fittings:—Horizontal slit (Fig. 2, C).
4 in. focus projection lens (Fig. 2, E).
Rotatable mirror.
Glass tank—water—fluorescein—light filter (green).
Room:—Dark.

(*g*) Illustrating (approx.) measurement of Refractive Index by the "Microscope Method."

The tank, filled with water, is mounted over the optical bench so that one of its end faces is in contact with the cross-line object (see Fig. 15). An ink spot is then made on the other end face of the tank and this mark projected on the screen with the 18 in. focus lens and the position of the latter recorded on the optical bench—[a bold scale on white cardboard pinned beneath the optical bench is desirable].—The tank is then removed

and the lens moved towards the cross line until the image of this is seen sharply focussed on the screen, the position of the lens again being recorded; this distance represents the "real" thickness of the water. On replacing the tank the cross-line is now projected on the screen after passage of the light through the water, the difference in reading of this last position of the lens and its first-named position

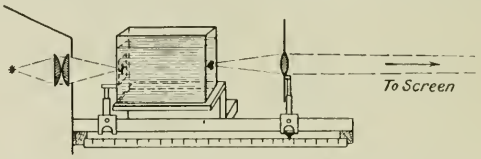


Fig. 15.—Approximate Refractive Index: "Microscopic" Method.

giving the "apparent" thickness of the water. Then refractive index $n = \frac{\text{real thickness}}{\text{apparent thickness}} \left(\begin{matrix} \text{very} \\ \text{approximately} \end{matrix} \right)$.

Apparatus:—Optical bench and projection lantern—2 saddles.
O.B. Fittings:—Cross-line object (Fig. 3, a).
Projection lens (18 in. focus) (Fig. 2, E).
Glass tank.
Bold black and white scale on cardboard.
Pen and ink.
Room:—Illuminated.

(*h*) Optical Smoke Box.

The value of the "optical smoke box," for demonstrating some of the experiments contained both in this and other sections, should not be overlooked. Such a piece of apparatus as Clarke's smoke box[1] can be of great service to the lecturer where small classes are concerned.

[1] Obtainable from G. Cussons, Ltd., Technical Works, Manchester.

IV

LENS AND MIRROR EXPERIMENTS

(*a*) Action of a Lens.

The action of a lens may be exhibited by what is known sometimes as the "swivelling lens" experiment. It consists in projecting on a distant screen the image of the grid filament of a high-power projection lamp by means of some twenty holes pierced in a piece of tinfoil which has been previously stretched over a circular metal frame 6 in. in diameter—see Fig. 16. To the top of this framework is attached a metal ring in which is mounted a lens of similar diameter and of approximately 20 in. focus, it being possible to rotate the lens eccentrically about its point of support, as shown in the figure. The distance between the tinfoil and the lamp filament should be such that before it is placed on the framework, the lens will form an image of the filament on the screen. With the tinfoil in position and the lens swung out of place the holes may be made (with a stout pin), when images will appear in different positions on the screen; if now the lens is swung *slowly* into position, it will be noticed how each patch of light is "picked up" or

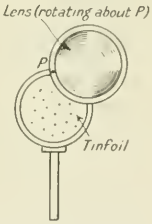


Fig. 16.—Optical Bench Fitting for Illustrating Action of a Lens.

"collected" by the lens and all made to coincide in one final image.

APPARATUS:—Optical bench—projecting lantern, but with usual condenser removed.
1 saddle.
Special O.B. fitting carrying swivelling lens.
Tinfoil—large pin.
ROOM:—Dark.

(*b*) Focal Length—Convex Lens.

Mirror Method. The cross-line object (Fig. 3, *b*) is illuminated by the projecting lantern and the above-mentioned lens (f. = 20 in.) mounted on the optical bench at a distance from the object approximately equal to its focal length. If now a plane silvered mirror be placed at M (Fig. 17) and the lens L be moved backwards and forwards, a position will be found where a back-reflected image of the cross-line is seen on the whitened surface at the back of the object O. When this is the case the distance LO represents the focal length of the lens, which can be measured up.

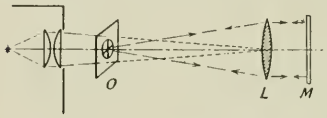


FIG. 17.—FOCAL LENGTH OF A POSITIVE LENS. MIRROR METHOD.

[The suggestion of using the 6 in. diam. lens is made with the idea of keeping the apparatus as large as possible in these experiments on lenses, so that students at the rear of the lecture room may appreciate better what is being done.]

Conjugate Foci Method. If the lens L in the above experiment is now moved to the end of the (metre) optical

bench, an image of the cross-line may be received on a translucent screen placed some distance along the lecture table; the lengths u and v (Fig. 18) can then be measured, and the relation $\frac{1}{v}=\frac{1}{u}+\frac{1}{f}$ thus verified experimentally.

[A simple yet effective way of taking measurements on the lecture table, in a manner in which all students can read them, is to stretch a piece of white tape between

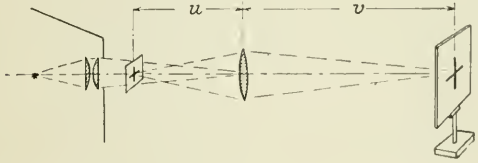


Fig. 18.—Focal Length of Positive Lens. Conjugate Foci Method.

the two points required and then to lay this on a previously marked out bold scale on the blackboard.]

Apparatus for above two experiments:—
Optical bench and projection lantern—3 saddles.
O.B. Fittings:—Lantern slide holder (Fig. 2, F).
Cross-line object (Fig. 3, *a* or *b*).
Wooden table (Fig. 2, D) with 6 in. square mirror standing on it.
6 in. diam. lens on stem L.
Translucent screen on stand (see Fig. 18).
Tape for measuring.
Room:—Illuminated.

(*c*) Focal Length.

Concave Lens. Using the 20 in. focus lens at the end of the optical bench, as in the preceding experiment, and forming an image of the cross-line at I_1 (Fig. 19), a large

concave lens may then be placed at N in the convergent beam and the new position of the image at I_2 recorded by means of the translucent screen. Measuring up $NI_1 = +u$ and $NI_2 = +v$ and applying these to the usual (thin lens) formula, the focal length of the negative lens may be determined. The negative lens and the screen will have to be held on individual stands—as the optical bench does not extend sufficiently far to carry out the experiment on a large scale, as it is best performed.

[An excellent translucent screen may be made by stretching a piece of draughtsman's tracing-paper or cloth

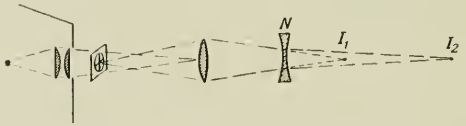


Fig. 19. Focal Length of Negative Lens.

over a wooden frame about 1 ft. square; moreover, being translucent, students both behind and in front of it are able to see images produced thereon.]

Apparatus:—Optical bench and projection lantern—2 saddles.
O.B. Fittings:—Lantern slide holder (Fig. 2, F).
Cross-line object (Fig. 3, *b*).
20 in. focus lens on stem.
Negative lens (12 in. focus—large diam. as possible).
Translucent screen on stand.
Tape for measuring.
Room:—Illuminated.

(*d*) Focal Lengths of Cylindrical and Sphero-cylindrical Lenses.

Similar experiments to the foregoing may be carried out with positive and negative cylindrical lenses, with the

exception that the cross-line object should be replaced by a small hole ($\frac{1}{4}$ in. diam.), as this renders the "line image" more apparent. As it is not always easy to procure a cylindrical lens of large diameter, it may be necessary to resort to the more convenient trial case lenses, in which case it is advisable to hold such lenses in the rotating mount B, (Fig. 2), so that the axis of the cylinder may be placed in any desired orientation. Assuming the average length of a lecture table as being 12 to 15 ft. and that the translucent screen is placed at the end of the table, a + 2·5 D. cylinder will be convenient to use for the positive lens, whilst a − 3 D. cylinder used in conjunction with the 8 in. focus projection lens is suitable for the negative cylinder experiment. The last-named fittings can both be mounted on the optical bench, the translucent screen being the only part to move along the table.

APPARATUS:—Optical bench and projection lantern—3 saddles.
O.B. Fittings:—Diaphragm with apertures (Fig. 2, A).
Rotating holder (Fig. 2, B).
Projection lens (Fig. 2, E), 8 in. focus.
Translucent screen on stand.
One +2·5 D. cylinder.
One −3·0 D. cylinder.
Tape for measuring.
ROOM:—Semi-darkened.

Sphero-cylindrical Lens. A convenient way of showing the action of a sphero-cylindrical lens and the two line foci at right angles to one another, is to use the $\frac{1}{4}$ in. diam. hole as the object and project in turn the image of this by a sphere (say +2 D.) and a cylinder (+2·5 D.

cyl.) separately and then combine them in one mount (see Fig. 20). If the translucent screen is placed at 76 in. from the hole (i.e. the object) in order to receive the image due to the sphere only, the screen can then be brought nearer to the combination until the second line

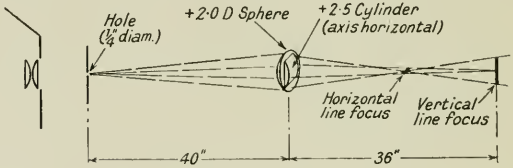


Fig. 20.—Action of Sphero-cylindrical Lens.

image (due to the resultant power of the sphere + the cylinder) is in focus.

Apparatus:—As for preceding experiment, but with addition of a +2 D. sphere.
A trial case will also be found of use, in the event of other lenses being required.

(*e*) Spherometer.

An experiment illustrating the principle of the spherometer may be carried out as follows:—In the path of the beam emerging from the condenser of the projection lantern is held in an inverted position an ordinary optician's "lens measure" (Fig. 21). The three "feet" of the latter are projected on the distant screen with a magnification of some 50 diameters (the 4 in. focus projections lens will be found suitable for this). If now a piece of sheet brass—having one straight edge and one edge with a radius turned on it of about 1½ in.—is pressed

in contact with the "feet" from below, the depression of the central foot will be illustrated clearly on the screen; the movement recorded being the sagitta of

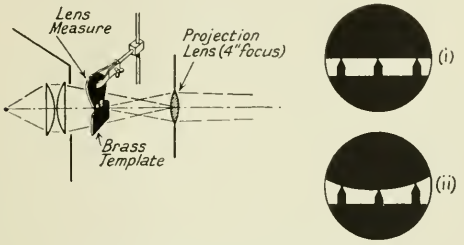


Fig. 21.—Illustrating Principle of Spherometer.
On the right, appearance seen on Screen.

the curved surface to be measured. The effect seen is depicted on the right of the figure—(i) the flat surface in contact; (ii) the curved surface in contact.

[It is instructive, when dealing with the meaning of the term "curvature" (i.e. the reciprocal of the radius of a surface), to have on the table wooden or white card segments (see Fig. 22) representing different curvatures, showing their respective sagittæ for the same chord in

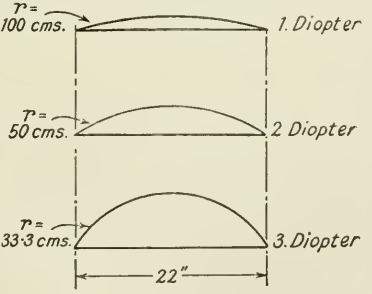


Fig. 22.—Curves for 1, 2 and 3 Diopters.

each case; for example, one, two, and three diopter curves.)

Apparatus:—Optical bench and projection lantern—1 saddle.
4 in. focus projection lens (Fig. 2, E).
Optician's lens measure.
Clamp for above on retort stand.
Brass template (as described).
Room:—Illuminated.

(*f*) Spherical Mirrors.

Convex Mirror; radius of curvature. Using the cross-line object (*a*, Fig. 3) and the 20 in. focus lens on the optical bench, an image of the former may be thrown on a screen placed at the end of the lecture table. By placing the convex mirror[1] M (5 in. diam. and approx. 20 in. radius), Fig. 23, in the convergent beam, and by

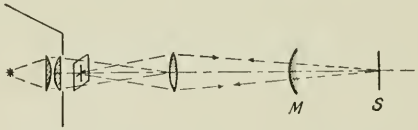


Fig. 23.—Radius of Curvature of Convex Mirror.

adjusting it backwards or forwards the position will be found when the rays striking the surface normally produce a back-reflected image of the cross-line on the whitened surface of the cross-line object. The distance MS (the radius of the mirror) can then be measured; its focal length being $\frac{r}{2}$.

[1] Such convex mirrors, mounted on an adjustable stand, can be obtained from firms supplying the usual physical apparatus, e.g., Messrs. Griffin & Tatlock, Kemble Street, Kingsway, London.

APPARATUS:—Optical bench and projection lantern—2 saddles.
O.B. Fittings:—Lantern slide holder (Fig. 2, F).
Cross-line object (Fig. 3, *a*).
6 in. diam. lens on stem (20 in. focus).
Translucent screen on stand.
Convex mirror (5 in. diam., 20 in. radius) on stand.
Tape for measuring.
ROOM:—Dark.

Concave Mirror; radius of curvature. To demonstrate the measurement of the radius of curvature of a concave mirror, the object (*b*, Fig. 3) should be used and illuminated (see Fig. 24), and a large concave mirror—suitably mounted—is then adjusted and moved to and fro along the axis until a reflected image is sharply focussed on the white back of the object plate. The

FIG. 24.—RADIUS OF CURVATURE OF CONCAVE MIRROR.

radius OM can then be measured up. It should be shown also that this image is an inverted one; this may be done by substituting the arrow-shaped object (*c*, Fig. 3) for the cross-line.

In order to make the experiment effective, it is desirable to use as large a mirror as possible—mirrors of 6 in. diam. and 6 ft. radius of poor optical quality (but not unsuitable for this and like experiments) may often be obtained quite cheaply.

Concave Mirror; focal length. Set up the object O (Fig. 25) and produce a parallel beam by means of the

lens L (6 in. diam., 20 in. focus). In this beam place the concave mirror, when the image of the cross-line can be received on a piece of white card or ground-glass screen ($1\frac{1}{2}$ in. in diam.) supported by a thin rod from the optical

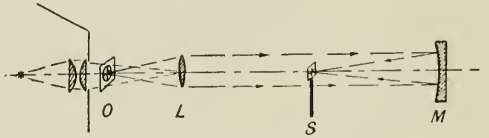


Fig. 25.—Focal Length of Concave Mirror.

bench. The distance SM represents the focal length of the mirror, and this value can be compared with that obtained by the previous experiment—i.e. by halving the radius there ascertained.

Apparatus for last two experiments:—
Optical bench and projection lantern—3 saddles.
O.B. Fittings:—Lantern slide holder (F, Fig. 2).
Cross-line object (*b*, Fig. 3).
Arrow-shaped object (*c*, Fig. 3).
6 in. diam. lens on stem (20 in. focus).
Concave mirror (preferably about 6 ft. radius) on stand.
Small piece of card or ground glass on thin rod (see S, Fig. 25).
Tape for measuring.
Room:—Dark.

(*g*) Aberrations of Lenses.

To illustrate to a class some of the forms of lens aberrations and to show the manner in which these defects affect the performance of a lens, will be found helpful for teaching purposes.

Spherical Aberration. This can be conveniently shown by making use of the 6 in. diam. (20 in. focus) lens

together with two cardboard or metal diaphragms, one in which there is a central hole 1 in. in diameter, and the other an opaque stop 4 in. in diameter. The lens—with the first-named diaphragm in front of it—is made to project an image of the small round hole ($\frac{1}{8}$ in. diam.) on to the screen at the side of the lecture room (see Fig. 26). [It is better to use a green screen in front of the object in order to render the light reasonably monochromatic.] The image received on the screen will thus be formed by axial rays passing through the lens; if now this stop is exchanged for the second one, only the marginal rays

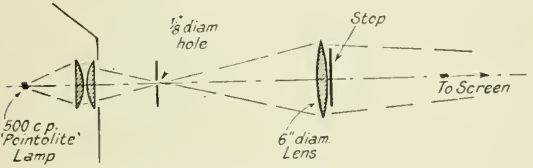


Fig. 26.—Aberration Experiments.

will be allowed to pass, and it will be found necessary to hold a screen some 18 in. to 2 ft. nearer the lens in order again to focus the image sharply. If both stops are removed it will be noticed how the general definition of the image is impaired due to the spherical aberration when using the lens at full aperture.

Chromatic Aberration. For this experiment a diaphragm (with a 3 in. hole in it) is placed in front of the lens—this reduces the spherical aberration sufficiently—and the image of the $\frac{1}{8}$ in. diam. hole (as object) is again focussed on the screen when using a red filter in front of the object. If the red filter is then exchanged for a

blue or violet one, it will be found necessary to hold a screen considerably nearer the lens to obtain a sharply focussed image, the distance between the two foci representing the chromatic aberration.

Astigmatism and Coma. If a round hole ($\frac{1}{4}$ in. diam.) be used as the object, and the lens (stopped down to 1 in. in diameter) is rotated about a vertical axis, the effect of the obliquity of the rays will be noticed on the image, both in the form of line foci and the defect "coma." By bringing the lens (thus inclined to the axis) nearer to the round-hole object, the tangential and sagittal line foci may be brought into sharp focus.

Distortion and Curvature of Field. These two aberrations may be illustrated by using a squared object *f*, Fig. 3—an opaque lantern slide with clear lines cut on it. If this is projected on the screen with a plano-convex lens of say 3 in. focus with its plane side towards the object, the distortion and curvature of field become very apparent. It is instructive to reverse the lens and again project the image, also to compare the effect when using a properly corrected photographic lens of the same *f* ratio.

Apparatus for aberration experiments:—
Optical bench and projection lantern—2 saddles.
Object holder (F, Fig. 2). Special objects: (1) Opaque triangle (*e*, Fig. 3). (2) Squares (*f*, Fig. 3).
6 in. diam. (20 in. focus) lens on stem.
3 cardboard or metal diaphragms.
Aperture plate (A, Fig. 2).
Light filters—red, green and blue.
Translucent screen.
3 in. diam. plano-convex lens.
Photographic lens.
Room:—Dark.

(*h*) Magnification by a Lens.

Employing object *d*, Fig. 3, and illuminating this in the usual way with the projection lantern, the 20 in. focus lens (6 in. diam.) can be used to project an image of the needles on a screen placed at the end of the lecture table. By then measuring the separation of the two needles in the image h' and their actual separation h, also the object and image distances u and v respectively, it can be shown experimentally that $m = \frac{h'}{h} = \frac{v}{u}$.

Apparatus:—Optical bench and projection lantern—2 saddles.
Object holder (F, Fig. 2).
Needle object (*d*, Fig. 3).
20 in. focus lens (6 in. diam.).
Translucent screen on stand.
Tape for measuring.
Room:—Dark.

Axial Magnification. Using the above lens and object and the translucent screen, arrange their distances such that an image of the needles is obtained magnified about five times and record the position of the translucent screen on the lecture table. Then carefully move the object 2 cms. nearer to the lens and move the screen away from the lens until the image of the needles is again seen sharply in focus. Measure the displacement of the screen, when it will be found that the ratio of this distance to the axial length of the object (namely 2 cms.) is proportional to the square of the lateral magnification $\frac{h'}{h}$.

(*i*) Lens Systems—two "thin" Lenses in contact.

In order to show that for two thin lenses in contact, the combined power is equal to the sum of the powers

of the individual lenses, the following experiment may be carried out:—A collimator C (Fig. 27) is first set up on the optical bench, the lens P being set at its proper position by means of the "mirror method" given in experiment (*b*) of this section. In the path of the parallel beam thus produced the lens L_1 (a + 1 D. trial case lens) is placed and the image of the cross-line received on the screen S_1—the distance L_1S_1 is measured by the tape method already described. A lens of similar power L_2 is then placed in contact with the first, and the resulting image sharply focussed by moving the screen into the

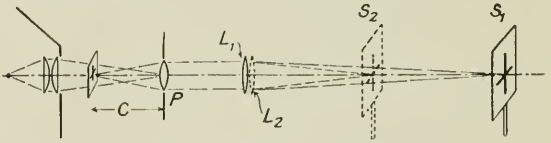


FIG. 27.—POWER OF "THIN" LENSES IN CONTACT.

position S_2, the distance $L_1L_2S_2$ again being measured, when it will be found that the latter focal length is half the former and therefore the dioptric power of the combination twice that of the one lens alone. Similarly, a + 2 D. lens may be combined with a − 1 D., and the relation $\mathcal{F}_{system} = \mathcal{F}_1 + \mathcal{F}_2$ again proved experimentally.

APPARATUS:—Optical bench and projection lantern—3 saddles.
O.B. Fittings:—Object holder (F, Fig. 2) with cross-line (*a*, Fig. 3).
Collimator lens, 8 in. focus (E, Fig. 2).
Clip for holding trial case lenses (H, Fig. 2).
Translucent screen on stand.
Trial case.
Measuring tape.
ROOM:—Semi-dark.

(*j*) Two "thin" Lenses separated by a distance "d."

An example demonstrating the meaning of "equivalent focal length" and "back focal length" of a lens system, together with an experiment verification of the relations $f_E = \frac{f_1 f_2}{f_2 + f_1 - d}$ and $f_B = \frac{f_2(f_1 - d)}{f_2 + f_1 - d}$, may be shown in the following way. The lens system L (Fig. 28) may be made up of two trial case lenses[1] A and B of +6 D. and −6 D. respectively, mounted on the steel rule fitting (shown in Fig. 42) and separated by a distance of 8·5 cms. If this be placed in the path of a parallel beam formed by

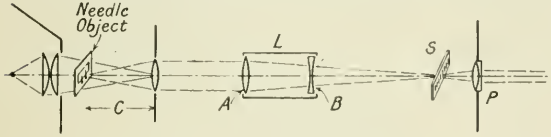


Fig. 28.—Two "Thin" Lenses Separated.

means of the collimator C an image of the two needles will be formed at S, the distance BS being the *back focal length*. If, then, a millimetre scale on glass [2] is placed at S, the scale and needles can be projected simultaneously on the distant screen by means of the 2 in. focus projection lens P, and consequently the linear separation of the needle images measured. The system L is then removed entirely and a single lens taken from the trial case (a+2·75 D.) is placed in the parallel beam and adjusted so that its focus coincides again with S. It will be found

[1] Small trial cases containing *unmounted* lenses suitable for this and other work are obtainable from Messrs. Gowlland, Morland Road, Croydon.

[2] Obtainable from Messrs. Rheinberg, 57/60 Holborn Viaduct, London, E.C.1.

that the image is the same size as that produced by the combination, and therefore the focal length of the single lens will represent the *equivalent focal length* of the system. If the focal lengths of A and B, obtained from their nominal powers, are substituted in the above formulæ together with the value of d, f_E and f_B can be worked out on the blackboard—a comparison being made between these figures and the results obtained experimentally.

Further, this experiment may be used as an illustration of the principle of the telephoto lens system.

Apparatus:—Optical bench and projection lantern—5 saddles.
O.B. Fittings:—Object holder (F, Fig. 2). Needle object (*d*, Fig. 3).
4 in. focus lens (E, Fig. 2).
Steel rule fitting (Fig. 42).
Clip (H, Fig. 2).
Millimetre glass scale.
2 in. focus projection lens (E, Fig. 2).
Trial case.
Room:—Dark.

(*k*) **Newton's Relation,** $xx' = -f^2$.

The practical application of this relation may be shown by making up a lens system from two $+1$ D. trial case lenses mounted on the steel rule fitting (Fig. 42) and separated by a distance of 20 cms.

It is first necessary to find the position of the two focal points F and F′ (see Fig. 29). This may be done by temporarily inserting one of the projection lenses (8 in. focus) at the correct distance from O such that OL forms a collimator and gives a parallel beam emerging from it (for this latter operation the "mirror method," exp. (*b*) of this section, is employed).

Thus, using a parallel beam incident on the lens

system the position of one of the focal points F′ can be determined and recorded. As the two lenses of the system are similar ones the position of F will lie at the same distance to the left of the front lens as F′ is to the right of the second lens.

For the sake of a lecture experiment it is convenient to use similar lenses for the system, although dissimilar ones may be used if desired; in which case F and F′ must be found individually by placing each end of the combination in turn towards the collimator.

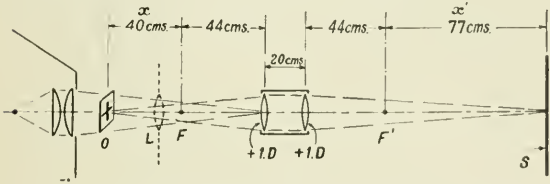


Fig. 29.—Newton's Relation. $xx' = -f^2$.

Having, therefore, fixed the two positions of F and F′, the collimating lens L is removed, and the object O moved so that OF = 40 cms. = $-x$. The translucent screen S is then brought in position until the image of O is sharply in focus, and the distance F′S = x' is measured up; the root of xx' will give the equivalent focal length of the system (55·5 cms.).

Apparatus:—Optical bench and projection lantern—3 saddles.
O.B. Fittings:—Object holder (F, Fig. 2).
Cross-line object (*a*, Fig. 3).
8 in. focus projection lens (E, Fig. 2).
Steel rule fitting (see Fig. 42) with two lens holders.
Two +1 D. trial case lenses.
Translucent screen on stand.
Measuring tape.
Room:—Semi-dark.

(*l*) Focal Depth of a Lens.

An experiment for showing this is illustrated in Fig. 30. An image of a special object O, consisting of a steel comb with well-spaced teeth, is projected on the distant screen by the 6 in. diam. lens L of 20 in. focus. The spacing of the teeth of the comb should be about $\frac{1}{4}$ in.—dog combs can be obtained of such a tooth interval as men-

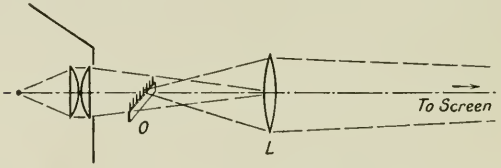


Fig. 30.—Depth of Focus Experiment.

tioned ; alternatively, a strip of wood into which some twelve pins are set at regular intervals may be employed.

This object O is held in a clip in one of the optical bench saddles so that it can rotate about a vertical axis. It is of interest first of all to show that by reducing the aperture of the lens its depth of focus is increased. This may be done by tilting the object through about 30 degrees from the normal position (i.e. 60° to the optical axis) and then focussing (by means of the lens) the *central* pin or comb tooth carefully on the screen. With the lens thus at full aperture it will be noticed that only one pin is in sharp focus; if now a diaphragm—having an aperture of $\frac{5}{8}$ in. diam.—is placed behind the lens, it will be seen at once that several of the pins appear in focus simultaneously, thus showing that the depth of focus is increased, and that it is dependent on the inclination of the image forming rays to the axis. If a large

iris diaphragm is available, the aperture of the lens can be *gradually* decreased and the corresponding effect noticed on the screen.

If it is wished to give a numerical example of the relation governing focal range in the image space, namely, Focal Range $= \frac{\lambda}{n' \sin^2 U'_m}$ where U'_m is the semi-angle of the marginal cone of rays forming the image, the distance from the lens to the screen must be measured and the semi-diameter of the lens-aperture, thus obtaining U'_m, from which the focal range or depth can be worked out on the blackboard. It can then be shown empirically that a movement of a screen over this calculated distance will not produce any perceptible change in focus of the image.

APPARATUS:—Optical bench and projection lantern—2 saddles.
Special object (as described).
Clip (H, Fig. 2) for holding object.
6 in. diam. lens, on stem.
Cardboard diaphragm with $\frac{5}{8}$ in. hole in it.
Or large iris diaphram, if available.
Measuring tape.
White card (2 ft. square) to act as a movable screen.
ROOM:—Dark.

(*m*) Thick Lens System.

In order to help the student to understand more readily the meaning of the "principal planes" of a lens system, the following experiment will be of service. A large and thick plano-convex lens (e.g., a large Bull's eye condenser) should be mounted on the optical bench with its plane side facing an incident parallel beam produced by a collimator, consisting of the 8 in. focus lens and needle object (*d*, Fig. 3). The 2 in. focus projection lens is then used first to project an image on the

screen of an ink-spot on the convex surface of the "thick lens"; it is then moved away from the latter until an image of the needles is seen sharply focussed on the screen, the distance moved by the projection lens representing the equivalent focal length of the "thick lens" (as one of the principal planes lies at the pole of the convex surface).

The "thick lens" is now turned round so that the convex side faces the incident light, and is moved backwards and forwards until the image of the needles is again sharply seen, the projection lens not being touched during this operation. An ink-spot is then made on the plane surface of the "thick lens" and the projection lens moved up until an image of the spot is seen on the screen, the distance moved by the projection lens again being recorded. The difference between the first and last named distances (moved by the projection lens) will give the position of the second principal plane with respect to the plane surface of the "thick lens," and hence the separation of the two principal planes.

It can further be shown that if the object and image distances are measured from these planes respectively, simple lens formulæ can now be employed.

The usual Gauss ray diagram for thick lenses will aid in the explanation.

Apparatus:—Optical bench and projection lantern—4 saddles.
O.B. Fittings:—Lantern slide holder (F, Fig. 2).
Needle object (*d*, Fig. 3).
8 in. focus projection lens.
2 in. focus projection lens.
Thick plano-convex lens (large).

V

PHOTOMETRY

(*a*) Inverse Square Law Model.

The wire pyramid model (Fig. 31), as made by any

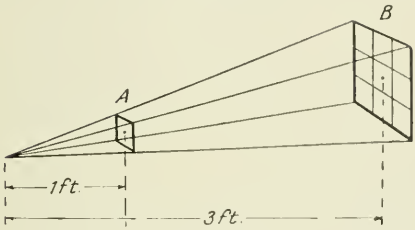


Fig. 31.—Inverse Square Law Model (in Wire). Illumination on B = $\frac{1}{9}$ that on A.

firm supplying physical apparatus, is a useful piece of apparatus for showing the relation $I = \frac{K}{d^2}$.

(*b*) Standard Sources of Light.

As many as possible of the following standards should be exhibited on the lecture table:—Standard sperm candle—Harcourt (pentane) standard—Hefner (amyl acetate) lamp—Electrical sub-standard (N.P.L.).

If the last three named are not available, lantern slides of the pentane and Hefner standards should be shown,

whilst Fig. 32 illustrates one of the National Physical Laboratories' sub-standard lamps.

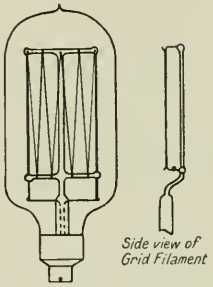


Fig. 32.—N.P.L. Sub-Standard Lamp.

(*c*) Photometers—types.

Some of the better-known types of photometer may be exhibited on the lecture table with advantage, such as: the (Bunsen) grease-spot, paraffin block (Joly), photoped, Lummer-Brodhun, Simmance-Abady flicker photometer.

(*d*) Photometer Experiment.

An experiment illustrating the use of a photometer may be shown to a class, by mounting an electric lamp (preferably with frosted or opal bulb) at each end of the metre optical bench and placing between them in another saddle a form of photometer head depicted in Fig. 33, *a* and *b*. This consists of two pieces of white card pinned to a base board as shown in plan view (*a*) and a third piece of card (blackened) with a circular aperture

in it, shown in front view (*b*). Such a model can be made on quite a large scale (as suggested by the dimensions in the diagram), and this enables students at some distance to judge the relative intensities of the two halves of the field. The lecturer can then move the photometer head to and fro along the optical bench until a "balance" is obtained; when this has been done, by assuming the candle-power of one lamp, that of the other may be determined by using the usual relation $\frac{K_1}{d_1^2} = \frac{K_2}{d_2^2}$.

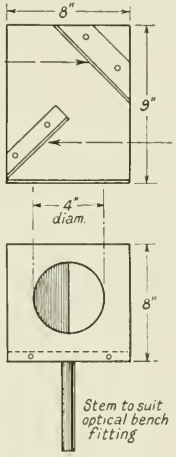


Fig. 33.—Simple Photometer Head for Class Demonstration.

Further, if a piece of neutral tint glass (or smoked glass) is interposed in one of the beams and the "balance" restored, the percentage absorption of the glass can be measured (approximately). If such an example is actually worked out in front of a class this tends to help students considerably.

Apparatus:—Optical bench—3 saddles.
2 Fullolite (opal) bulbs, each housed in a cylindrical (cocoa) tin with a circular hole cut in the side (the purpose of this is to prevent stray light going out into the room).
Photometer model (as described).
Piece of neutral tint or smoked glass (4 in. square).
Clip for holding this (H, Fig. 2).
Measuring tape.

Room:—Dark.

(*e*) **Polar Curves (Experiment).**

If one of the opal bulbs (in the above experiment) is

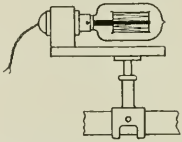
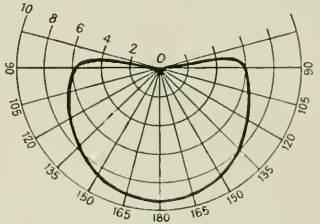
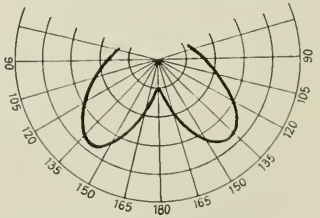


Fig. 34.—Rotating Lamp Holder in Optical Bench Saddle for Photometer Experiments.

replaced by a clear glass electric lamp, and the latter is made to rotate in a horizontal plane by means of a suitable



(*a*) Gas-filled Electric Lamp fitted with reflector.



(*b*) Open Arc Lamp.

Fig. 35.—Light Distribution Plotted on Polar Co-ordinates:—Concentric Circles represent Candle Power. Radial Lines represent displacement from the Vertical Direction.

mount (see Fig. 34), the candle-power for various orientations of the lamp can be measured and a curve plotted on polar ordinates. Such curves are shown in Fig. 35, *a* and *b*.

(*f*) Rumford Photometer.

This is also a convenient type of photometer to show to a class, as again all members will be able to see the experiment clearly. The previously mentioned two "Fullolite" bulbs (housed) may be used in conjunction with a 2 in. diam. cardboard tube (i.e. the "rod"). The two shadows of the latter which are made to lie side by side are received on the translucent screen facing the class—the arrangement of the apparatus is similar to that in Fig. 8, except that S_1 and S_2 are further separated so that only the penumbral shadows are seen on the screen. If then one of the sources of light is moved backwards, the change in relative luminosity of the shadows will be clearly seen.

Apparatus:—Two "Fullolite" electric bulbs in housings.
Cardboard tube (2 in. diam.) (postal tube).
Translucent screen.
Room:—Dark.

(*g*) Illumination Photometers.

Mention should be made of this type of photometer, in which the illumination at a given position is determined by comparing the brightness of a white surface placed in this position with that of another surface contained in the instrument. If one of these photometers, such as for example the Lumeter, is available, it should be exhibited and described.

VI

THE EYE

(*a*) Working Model of Human Eye.

For lecture work on the eye, whether dealing with it as an optical instrument or from a physiological point of view, a good diagram or lantern slide is the first essential.

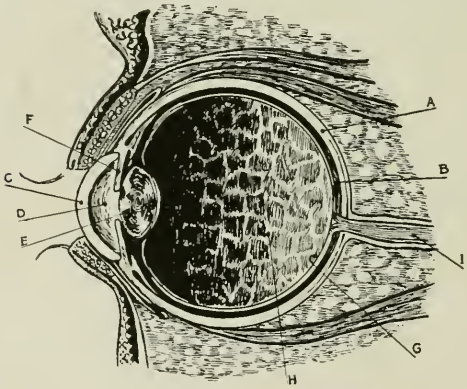


Fig. 36.—Human Eye—Vertical Section.

A—Sclerotic, B—Choroid, C—Cornea, D—Aqueous Humour, E—Crystalline Lens, F—Iris, G—Retina, H—Vitreous Humour, I—Optic Nerve.

Such a diagram, showing a vertical section of the eye, is given in Fig. 36, from which a lantern slide may be made.

The action of the eye (treated as an optical instrument) can be well illustrated by having a working model of it

before the students. Such a model[1]—originally due to Professor F. J. Cheshire and constructed by the author—is shown in Fig. 37, and diagrammatically in Fig. 38. It consists of a metal tube T, at one end of which is a lens L_1 (20 cms. focus) (representing the crystalline lens of the human eye), whilst at the other—situated at the focus of L_1—is a piece of clear glass on which is painted

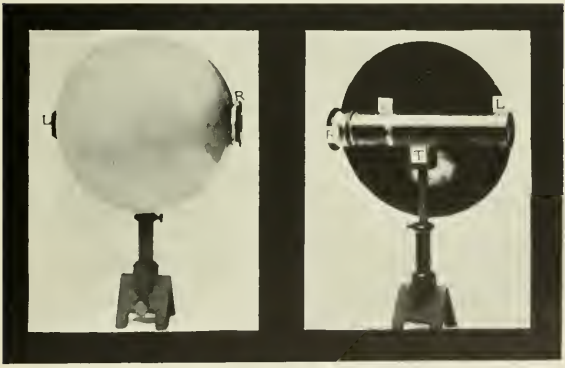


Fig. 37.—Working Model of the Human Eye.

some pigment cells or blood-vessels to represent the retina. The lens P is merely for projecting an image of the retina on to the distant screen, so that the class sees as a whole what one would see if it were possible to view the back of a living person's eye.

For example, one of the first experiments that can be carried out, is to reproduce the case of a normal relaxed

[1] *Optician and Photographic Trade Journal*, Oct. 23rd, 1908.

eye viewing a distant object. This can be done by placing a collimator C (Fig. 38) on the optical bench in front of the model eye, and by illuminating the object of the collimator with the projection lantern in the usual way, an image of this object (*e*, Fig. 3) will be formed on the retina of the model eye. The projecting lens P will then throw an image of the retina together with the image of *e* simultaneously on to the screen.

The model eye is further fitted with an auxiliary lens L_2 (39 cms. focus), which is capable of sliding backwards or forwards inside the tube T, so that by altering the separation between the two lenses L_1 and L_2 their com-

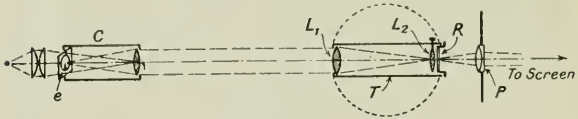


Fig. 38.—Action of Model Eye (Diagrammatic).

bined power may be changed at will (the power being greatest when the two lenses are in contact), and thus the effect of "accommodation" can be reproduced. If, therefore, the collimator is removed and a transparent object (such as a lantern slide of a page of print) is alone mounted as far in front of the "eye" as the optical bench will permit, the auxiliary lens L_2 can be moved along the tube T until the "page" of print is in focus on the retina and therefore also on the screen. Now move L_2 until it is in contact with L_1, thus giving the full accommodating power of the eye, then the print object will have to be moved slowly towards the eye, a position being reached when it is focussed on the retina, this position being the

"Near Point" of the model eye. Two other retinæ mounted in slightly longer and shorter lengths of draw-tube can be placed when desired in the end of the tube at R, so that the positions of the "Near Points" can also be determined for cases when the "eye" is myopic or hypermetropic respectively.

(*b*) **Correction with Spectacle Lens.**

The correction of an ametropic eye by the use of a trial case may also be conveniently demonstrated with the apparatus. If the draw-tube which brings the retina *farther* from the lens is pushed in at the end R of the tube T (thus reproducing the case of myopia) and the collimator placed in front of the eye as before, it will not be found possible to focus the distant object on the retina. But by placing various weak negative lenses (from the trial case) in turn in front of the model eye, one will be found which brings the distant object in focus on the retina, this being, of course, the correcting lens required.

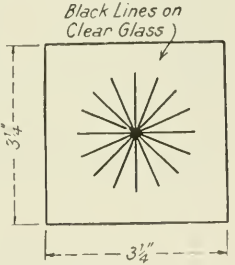


Fig. 39.—Radial Line Object for Model Eye Experiments.

A similar experiment may be done using the other retina representing the case of hypermetropia, and correcting with a positive lens.

Astigmatism. If a weak minus cylinder (—0·25 D.) (mounted in a cap which pushes over the front of the model eye) is used with the "eye" fitted with the *normal*

retina, and the "eye" is made to view a radial type object—see Fig. 39—situated at the "near point," it will be noticed how the image on the retina (and therefore on the screen) appears sharply in focus in one meridian whilst being ill-defined in others. By choosing a plus cylinder from the trial case, holding it in front of the model eye and giving it its correct orientation, the "eye" suffering from astigmatism may be corrected.

Either of the other two retinæ may then be used, in which case both a sphere and a cylinder will have to be employed for correcting the vision of such an eye, thus illustrating the principle of the sphero-cylindrical spectacle lens.

APPARATUS:—Optical bench and projection lantern—5 saddles.
O.B. Fittings:—Model Eye—3 retinæ.
2 in. focus projection lens.
Lantern slide holder (F, Fig. 2).
8 in. focus lens and object (*e*, Fig. 3) for making up collimator.
Mount for holding trial case lenses (K, Fig. 2).
Rotating lens holder (B, Fig. 2).
Transparency of page of print and radial object (Fig. 39).
Trial case.
ROOM:—Dark.

VII

OPTICAL INSTRUMENTS

The principles of some of the simpler optical instruments will be more readily understood if the usual blackboard drawing is accompanied by working models of such instruments.

(*a*) **Refracting Telescopes.**

Both the Galilean and astronomical types can be clearly

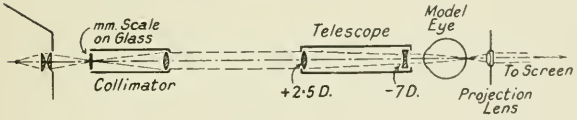


Fig. 40.—Action of Galilean Telescope.

illustrated by making these up with trial case lenses and using them in conjunction with the model eye. Figs. 40

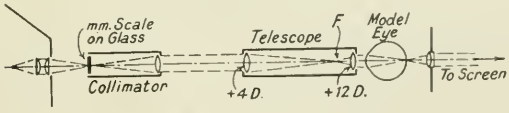


Fig. 41.—Action of Simple Astronomical Telescope.

and 41 show diagrammatically the arrangement of the optical systems in this experiment. The diagrams will

be found self-explanatory, the lenses used in the two types of telescopes being indicated. It is better, first of all, to allow the model eye to view the distant object (i.e. artificially produced by the collimator) unaided, and then to place the telescope—already focussed for infinity—in front of the "eye," when the magnification produced by the interposing of the instrument becomes readily apparent. Incidentally, a value for this magnification can be obtained by measuring up the size of the images of the projected millimetre scale

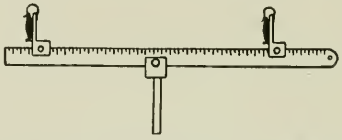


Fig. 42.—Optical Bench Fitting for Carrying Working Models of Telescope and Microscope.

both before and after the instrument is placed in front of the "eye."

The above-mentioned telescopes may be conveniently made up by holding the trial case lenses in suitable mounts which slide along a steel rule (say 20 in. long)—such a fitting is shown in Fig. 42.

When the apparatus is set up for the simple astronomical telescope, it is of interest to demonstrate the action of two devices which are in general use in telescopes, namely (1) the field lens, and (2) the erector as used for terrestrial telescopes.

The former may be shown by inserting a + 10 D. lens at the point F (Fig. 41), when the effect will be at once

visible on the screen. The action of the latter may be demonstrated by holding an erector (which has been temporarily removed from a terrestrial telescope) with its front lens slightly in front of the point F (Fig. 41), when the inversion of the previous image will become apparent.

Ramsden Circle. The existence of the Ramsden circle may be shown by using the apparatus in Fig. 41, removing the model eye and collimator entirely, and bringing up the 2 in. focus projection lens nearer to the telescope until an image of the Ramsden circle is sharply focussed on the screen. That this is an image of the telescope object glass formed by its eyepiece may be illustrated by holding any sharp-pointed instrument against the objective (i.e. the +4 D. lens), when this point will be seen in focus on the screen simultaneously with the Ramsden circle. Further, if a millimetre scale on glass be placed in the plane of the Ramsden circle, the diameter of the latter can be obtained by observing the projected image. This diameter divided into the diameter of the object-glass will give the magnification of the telescope.

APPARATUS:—Optical bench and projection lantern—6 saddles.
O.B. Fittings:—Clip (H, Fig. 2) holding millimetre scale on glass. } Together making the collimator.
8 in. focus lens (E, Fig. 2). }
Model Eye.
Steel rule fitting (Fig. 42).
Trial case.
2 in. focus projection lens.
ROOM:—Dark.

(*b*) **Reflecting Telescope.**

The type taken to represent this form of telescope is the Newtonian. A collimator C (Fig. 43) should be made up on the optical bench employing the 6 in. diam. lens and needle object and illuminated with the projection lantern. At some distance farther along the lecture table the reflecting telescope is set up—this consists of a 6 in. diam. front-surface-silvered concave mirror M_1 (of say

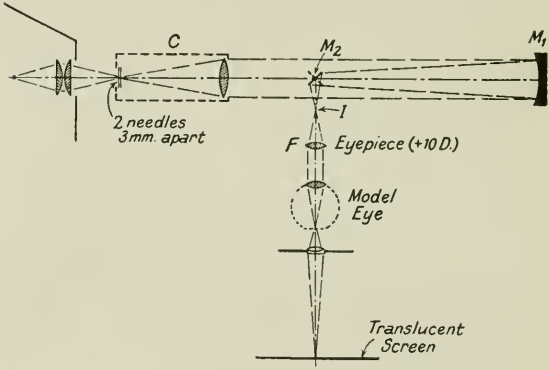


Fig. 43.—Reflecting Telescope. Newtonian Type.

3 ft. focus) not necessarily of high quality, a small flat mirror M_2 (1 in. square) and an eyepiece F (a +10 D. trial case lens). For convenience' sake these can be mounted and adjusted on a wooden baseboard, thus making the telescope a complete unit in itself.

The model eye (unaided) is first made to view the distant collimated object by rotating M_2 into the position shown dotted and removing the eyepiece F, the image

on the retina of the model eye being projected on the translucent screen facing the class. M_2 is then rotated to its original position and F replaced, when an image of the object will be formed at I, which is in turn observed by the eyepiece and model eye and finally projected on the ground-glass screen as before. The increased separation of the needles (as observed on the translucent screen) in the last case will be clearly visible, thus illustrating the effect of the telescope; the ratio of the latter separation to the former will give the magnifying power of the instrument.

APPARATUS:—Projection lantern and 2 optical benches—5 saddles.
O.B. Fittings:—Lantern slide holder (F, Fig. 2).
Needle object (needles 3 mm. apart).
6 in. diam. lens on stem.
Model eye.
2 in. focus projection lens.
Newtonian telescope as described.
Translucent screen on stand.
ROOM:—Dark.

(c) Microscope—(Simple Magnifier).

The action of the "simple microscope" or "hand magnifier" can be illustrated with the model eye as indicated in Fig. 44. The latter, fitted with the normal retina, should be made to view the millimetre scale on glass at its "near point," that is by giving the model eye its full accommodating power (this is done by bringing L_2 of Fig. 38 as close to L_1 as possible). The image of the scale is formed on the retina and is projected on the screen by the 2 in. focus projection lens, the size of (say) five divisions being measured up.

If now a +6 D. or +7 D. lens be placed immediately

in front of the "eye" and the glass scale moved towards this lens, a position will be found when the scale is again in focus on the retina; and it will be noticed how much larger the image of the scale appears on the screen. The ratio of the size (as measured on the screen) of the same

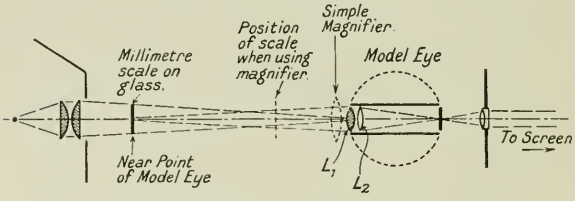


Fig. 44.—Showing Action of Simple Magnifier with Model Eye.

object interval seen by the model eye unaided and with the "magnifying lens" will give the magnification produced; this value can be compared with the result obtained by dividing the "distance of distinct vision" of the model eye by the focal length of the "magnifying lens."

Apparatus:—Optical bench and projection lantern—4 saddles.
O.B. Fittings:—Model eye—normal retina fitted.
Clip (H, Fig. 2).
Lens mount (K, Fig. 2).
2 in. focus projection lens.
Millimetre scale on glass.
Trial case or a +6 D. and +7 D. lens.
Room:—Semi-dark.

(*d*) Microscope (Compound).

Fig. 45 illustrates the method of demonstrating the principle of the compound microscope. The millimetre

scale on glass S is illuminated by the projection lantern. The microscope consists of an objective O and eyepiece E mounted on the steel rule fitting shown in Fig. 42, the lenses employed being two +12 D. lenses from a trial case. The model eye (with full accommodating power) is then placed behind the eyepiece, so that the Ramsden circle (or Exit Pupil) falls *on* the lens of the model eye, when by slight adjustment of E the final image will be focussed on the retina, which in turn is projected on the screen by the lens P. An actual figure for the magnifying power thus obtained can be arrived

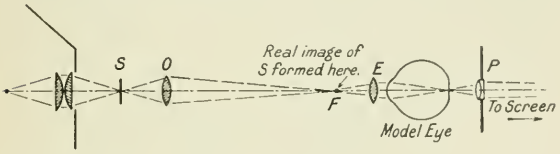


Fig. 45.—Compound Microscope.

at by measurement of a number of divisions of the scale, as seen on the screen both when the apparatus is set up as just described and when the compound microscope is entirely removed from in front of the model eye, and dividing the former by the latter. If the lenses used for the microscope (and for the model eye) are those suggested in the text, it will be found that S will be at the "near point" for the eye when the microscope is removed. The "primary magnification" can also be measured by placing a second glass scale at the point F and projecting this together with the "real" image of S on to the screen when the model eye and the lens E have been removed.

Apparatus:—Optical bench and projection lantern—5 saddles.
O.B. Fittings:—Model eye (fitted with normal retina).
2 in. focus projection lens.
2 clips (H, Fig. 2).
2 glass scales.
Steel rule fitting (Fig. 42).
Two +12 D. lens from trial case.
Room:—Dark.

(*e*) Projection Lantern (and Enlarger).

For clearness' sake, it will be found best to set up the individual parts of the projection lantern separately on the optical bench, as the student then has the instrument before him without the disadvantage of the components being hidden by casings or metal tubes; moreover, the

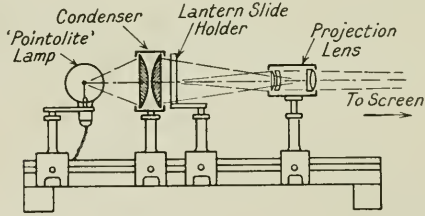


Fig. 46.—Projection Lantern adapted for Optical Bench Fitting.

effect of moving one or any of the parts relatively to one another can easily be accomplished and the resulting effect noticed. Fig. 46 shows the optical bench with the lantern made up as indicated by the named parts. An experiment showing the application of the formula $m = 1 - \frac{v}{f}$ to this instrument may be carried out by first determining numerically on the blackboard the expected

magnification for a given distance of the screen (say the limits of the lecture-room) and then inserting in the lantern slide holder a piece of clear glass with two black lines on it 1½ in. apart and measuring up the separation of their projected images.

Also, a certain magnification can be decided on and the position of the screen calculated; this being verified in practice by observing the position of the sharply focussed image on a movable screen or piece of white card. A magnification of fifteen times will be found a suitable choice in the second experiment.

APPARATUS:—Optical bench—4 saddles.
O.B. Fittings:—100 c.p. "Pointolite" lamp on bracket (see Fig. 46).
Condenser (see Fig. 46).
Lantern slide holder (see Fig. 46).
8 in. focus projection lens (E, Fig. 2).
Measuring tape.
ROOM:—Dark.

(*f*) Opaque Projection.

Opaque projection may be shown in the lecture room and again in a way which does not hide the various optical parts from the class—such as does the modern epidiascope. Fig. 47 shows the method of doing this, which has proved quite successful in spite of the difficulties of illumination. A is the usual projection lantern, containing in this case a 10-ampere arc. An approximately parallel beam emerging from the latter is reflected downwards by the silvered mirror M_1 on to the table. In the brightly illuminated area of light thus produced is placed a white card on which are some boldly printed letters about 1 in. high (such as the word "optics"). If now

a lens L (3 in. diam. and 24 in. focus) be held in a clamp immediately above the card and a right-angled prism M_2 placed as indicated, an image of the opaque object can be satisfactorily projected on the screen some 15 to 20 ft. away. It is interesting to show the necessity of the reflector M_2 and its reversing action, by removing the latter entirely and observing the image projected directly

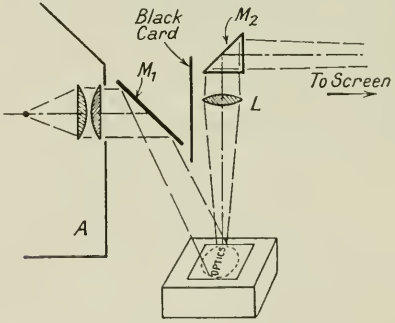


Fig. 47.—Opaque Projection.

on to the ceiling. A coloured diagram may also be used if a further example is desired. (The piece of black card in the position shown in the figure is very necessary in order to prevent stray light from reaching the screen.)

Apparatus:—Projection lantern—10 or 15 amp. arc.
Piece of silvered mirror, 7 in. × 5 in.
Lens, 3 in. diam., 24 in. focus.
Retort stand for holding the above lens.
Right-angled prism—3 in. face.
White card with bold letters on it.
Coloured object.
Room:—Dark.

VIII

THE SPECTRUM AND COLOUR

(*a*) The Spectrum—Newton's Experiment.

Newton's original experiment showing the formation of the solar spectrum, may be reproduced in the lecture-room as shown in Fig. 48. The round hole ($\frac{1}{3}$ in. in diam.) is illuminated by light from the projection lantern

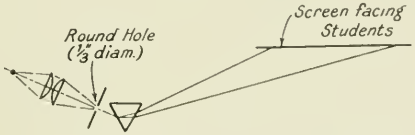


Fig. 48. Simple Spectrum. Newton's Experiment.

and a 60° glass prism held in the beam, the spectrum being received on a distant screen facing the class. The spectrum will be "impure" owing to the overlap of the circular images of the various colours.

Apparatus:—Projection lantern.
Optical bench—2 saddles.
O.B. Fittings:—Metal plate, $3\frac{1}{4}$ in. square, with hole in it, $\frac{1}{3}$ in. diam.
Lantern slide holder (F, Fig. 2) for above.
Small table (D, Fig. 2).
60° glass prism (poor quality).

Room:—Dark.

If a more elaborate representation of this historical

experiment is required, an artificial sun may be substituted for the projection lantern, thus ensuring that the spectrum produced is approximately of the same dimensions as the original. The artificial sun consists of a collimator (see Fig. 49) which has as an object a small round hole, the

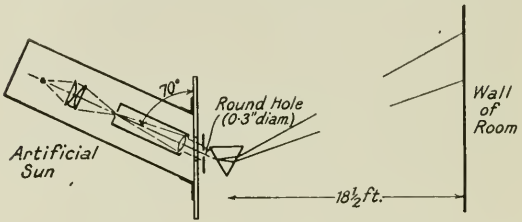


Fig. 49.—Elaborated Method of Performing Newton's Original Experiment.

diameter of which is such that it subtends an angle of half a degree at the collimating lens (i.e. the angle subtended by the sun at the earth). The optical arrangement for the experiment will then be as depicted in the diagram (Fig. 49).

(*b*) Purer Spectrum for General Use.

For the general projection of a spectrum, however, it will be found more convenient to use a slit S (Fig. 50), the 4 in. focus projection lens L, and a hollow 60° prism P

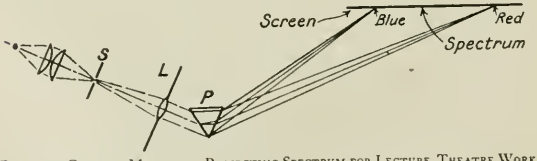


Fig. 50.—General Method of Projecting Spectrum for Lecture Theatre Work.

filled with carbon disulphide instead of a solid glass prism, as the former will give a longer spectrum due to the greater dispersion produced.

APPARATUS:—Optical bench and projection lantern—3 saddles.
O.B. Fittings:—Slit (C, Fig. 2).
4 in. focus projection lens (E, Fig. 2).
Small table (D, Fig. 2).
Hollow 60° prism filled with carbon disulphide.

ROOM:—Dark.

(*c*) Line Spectra.

In the foregoing experiment, if some substances, such as copper filings, zinc chloride or lithium chloride, be placed in a hollowed-out recess in the lower pole of the carbon arc, certain prominent lines (characteristic of the particular element) will be seen on the screen; it is thus possible to render *line* spectra visible to the class as a whole—the lines, however, will be superimposed on the continuous spectrum. If a purer line spectrum is desired, a mercury arc lamp or an arc using pure metals for the poles (such as copper or silver) may be employed as the source with successful results; alternatively the method suggested in (*k*) of this section will serve.

APPARATUS:—As for foregoing experiment, but arc lamp with a few carbons hollowed out to carry:—
(*a*) Copper filings.
(*b*) Lithium chloride.
(*c*) Rods of pure copper or silver.

ROOM:—Dark.

(*d*) Spectral Colours are Fundamental Colours.

An interesting experiment (also due to Newton) to illustrate the fact that, when white light is split up into

its various component colours, these colours are fundamental ones, can be shown by arranging the apparatus as in Fig. 51. The spectrum formed by the prism P_1 is allowed to fall on a piece of card which has a slit about $\frac{3}{8}$ in. wide pierced in it, and a certain colour (say red) is

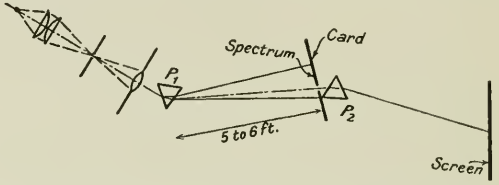


Fig. 51.—Experiment showing that the Spectral Colours cannot be further Split up.

allowed to pass through. If now a second prism P_2 is placed as indicated, a red patch of light will be seen on the final screen, thus showing that any particular spectral colour cannot further be split up.

Apparatus:—Optical bench and projection lantern—3 saddles.
O.B. Fittings:—Slit (C, Fig. 2).
4 in. focus projection lens (E, Fig. 2).
Small table (D, Fig. 2).
Hollow 60° prism filled with carbon disulphide.
Piece of white card, 3 ft. × 2 ft., with
slot cut in it, 3 in. high × $\frac{3}{8}$in. wide.
Glass 60° prism (preferably flint).
Room:—Dark.

(*e*) The Colour of Objects.

The reason that the colour of objects seen in white light is due to the reflection by the object of certain spectral colours and to the absorption of others, can be clearly explained by holding coloured papers or ribbon

in different parts of a spectrum projected on the screen. For instance, if we take a piece of white card with (matt) red paper stuck over half of it (see Fig. 52) and pass it into the spectrum from the red end we shall notice that as soon as the red paper is moved on into other parts of the spectrum it no longer appears red but black, showing that only red light is reflected by the object, the other colours being absorbed. Similarly, green and blue cards may be passed through the spectrum and the appearances observed.

APPARATUS:—As for experiment (*b*) of this section with the addition of coloured papers or ribbons.
ROOM:—Dark.

(*f*) Colours by Transmission.

With the spectrum projected on the screen as before, the absorption of colour by passing light through certain coloured glasses or liquids may also be shown. If, for

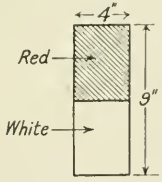


FIG. 52.—WHITE CARD HALF COVERED WITH (MATT) RED PAPER.

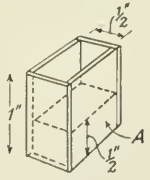


FIG. 53.—PLATE-GLASS CELL.

instance, a red screen is held in front of the slit the red portion of the spectrum will be seen on the screen whilst the remainder will be suppressed; similarly, the effect of interposing a blue screen may be observed. It is of

interest to hold a violet filter in front of the slit and so see how the red and blue portions of the spectrum are transmitted, and the remainder extinguished. If a selection of light filters (as supplied by Messrs. Kodak) are available, other interesting absorption and transmission effects will be observed. Liquids may also be used by holding them in a cell [1] made up in plate-glass as indicated in section in Fig. 53; if this is placed such that the upper edge of the glass block A bisects the slit horizontally, the effect seen on the screen is that of two adjacent spectra, one being due to light which has passed unaffected through the glass, and the other after passage through the liquid; in this way the comparison of transmission is more readily observed. Good examples of liquids for such a lecture experiment are: (1) weak solution of permanganate of potash (transmitting red and blue), (2) solution of fluorescein (effectively stopping blue and violet), (3) chlorophyll, (4) human blood diluted.

Apparatus:—As for experiment (*b*) of this section with the addition of (1) several coloured glasses,
(2) liquid solutions as described,
(3) glass cell (Fig. 53).
Room:—Dark.

(*g*) Setting-sun Experiment.

An old but excellent experiment illustrating the gradual absorption of the component colours of white light (beginning with the blue) may be demonstrated by reproducing a sunset, showing why it is that we see the sun "going down" at evening-time with a reddish hue.

[1] A suitable cement for this purpose is litharge and gold-size mixed to a paste.

Fig. 54 illustrated the method of doing this. A circular aperture A ($\frac{3}{4}$ in. diam.) is illuminated by the usual projection lantern and a *badly* focussed image of the former is thrown on to a translucent screen by means of the 2 in. focus projection lens at a distance of about 4 ft. A straight-edge B is placed on one side and across the diameter of the aperture (but not touching it) so as to give the appearance on the screen of the horizon. Between the lantern condenser and the circular aperture

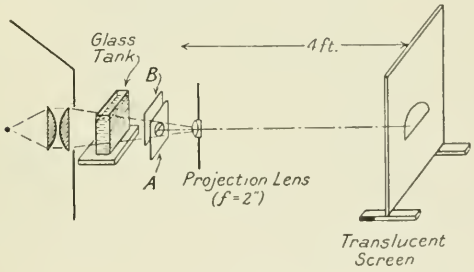


Fig. 54.—Setting-sun Experiment.

there is placed a glass tank (about $1\frac{1}{2}$ in. in width), which is filled with a solution of hyposulphite of soda (see below). If now a little dilute hydrochloric acid is added drop by drop, a precipitate will gradually be formed, the suspended particles of which slowly absorb the light passing through the solution, but as the shorter wavelengths are absorbed first the projected "sun" on the screen gradually takes a yellow colour and as the precipitation goes on the colour changes to orange, red, deep red, and finally is extinguished altogether, thus repro-

ducing the effect of a sunset. If desired, the circular aperture may be very slowly moved upwards in its optical bench fitting, giving the appearance on the screen of the sun "going down."

Hyposulphite Solution.		Hydrochloric Acid Solution.	
Saturated Solution of Hypo.	10 c.c.	Hydrochloric acid (pure).	1 c.c.
Water	200 c.c.	Water	10 c.c.

Apparatus:—Optical bench and projection lantern—3 saddles.
O.B. Fittings:—Circular aperture ($\frac{3}{4}$ in. diam.).
2 in. focus projection lens (E, Fig. 2).
Small table (D, Fig. 2).
Glass cell for hyposulphite solution.
Dropping bottle for hydrochloric solution.
Translucent screen.
Room:—Dark.

(*h*) Colour-mixing Experiments.

An experiment for demonstrating complementary colours and the mixing of colours either by addition or subtraction is shown diagrammatically in Fig. 55. The collimator illuminated by the usual projection lantern

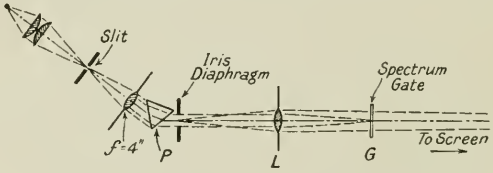


Fig. 55.—Apparatus for Colour-mixing Experiments.

gives a parallel beam incident on the carbon-disulphide prism P. An iris diaphragm is placed in the emergent beam as near to the second face of the prism as possible, and the 8 in. focus projection lens L forms an image of this iris on the distant screen—this image will appear

white if the adjustment is correct. At the point G—i.e. the second principal focus of the lens L—is placed a brass strip with a rectangular aperture in it (see Fig. 56), called here a spectrum "gate." As a sharply focussed spectrum is formed in this plane, any portion of it may be excluded from passing to the final image on the screen by placing small strips of brass (such as at Fig. 56, *a*) in any desired part of the spectrum. Thus the colour of the patch on the screen will be altered from white to

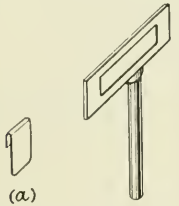


Fig. 56.—"Spectrum Gate."

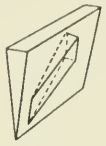


Fig. 57.—Method of obtaining "Skew" Prism.

a colour dependent on the spectral colour or colours removed by the brass shutter at the spectrum gate. A further instructive part of the experiment is to substitute for the brass shutters one or more *skew* prisms—such prisms being obtained by cutting a strip from a small-angled prism as indicated in Fig. 57. In this way, additional coloured images of the iris will be seen, the colour depending on the position of the skew prism in the spectrum. By opening the iris diaphragm, the coloured images may then be made to overlap, when the resulting white of the overlapping portion will be observed.

Apparatus:—Optical bench and projection lantern—6 saddles.
O.B. Fittings:—Slit (C, Fig. 2).
4 in. focus projection lens (E, Fig. 2).
8 in. focus projection lens (E, Fig. 2).
Small table (D, Fig. 2).
Carbon-disulphide prism.
Iris diaphragm (I, Fig. 2).
Spectrum gate (Fig. 54).
Small brass strips and skew prisms.
Room:—Dark.

(*i*) Radiations other than the Visible Spectrum.

The diagram shown in Fig. 58 will be found useful for putting on the blackboard.

The Ultra-violet. The presence of this invisible portion of the spectrum may be shown by projecting the spectrum in the ordinary way, as in Fig. 50, but by using a

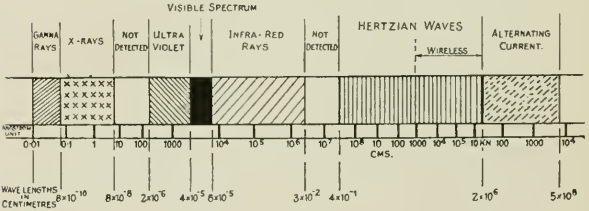


Fig. 58.—Diagram for Blackboard. Map of Radiations, Visible and Invisible.

carbon (or preferably an iron) arc as the source of light, and then holding certain substances in the region immediately further on than the visible violet, when these substances will fluoresce. Suitable objects for this purpose are:

(1) Block of uranium glass.

(2) A barium platino-cyanide screen.

(3) Vaseline smeared on black paper.

(4) Salicylate of soda crystals (stuck on to a card).

(5) Aqueous solution of quinine sulphate.

(6) Mineral oils will fluoresce, but animal and vegetable oils will not.—Smear a drop of each on black paper and compare.

An alternative method which gives perhaps rather better results is to use the apparatus shown in Fig. 59, in which A is the arc, B the usual condenser, and C a piece of Chance's ultra-violet transmitting glass ($\frac{1}{8}$ in. thick). An enlarged image of the arc-crater is formed

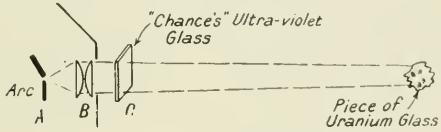


Fig. 59.—Method of Demonstrating Fluorescence.

on the screen by the condenser B and the glass C then interposed in the beam. This glass has a black appearance and will transmit very little of the visible part of the spectrum, so that all the light arriving on the screen (namely the ultra-violet) is invisible, but immediately one of the previously mentioned objects is placed in this patch of light, it fluoresces and becomes visible, whereas if moved to one side it cannot be seen at all.

Apparatus:—Arc lamp in lantern with condenser.
Piece of Chance's U.V. glass and holder for same.
Objects as described above.
Room:—Dark.

The infra-red. In order to show the existence of the infra-red region, a spectrum is projected on the screen

as shown already in Fig. 50, employing a 10 or 15 amp. arc as the source; and in the invisible portion beyond the red is placed a thermopile and the usual electrical connections made to a galvanometer. The general arrangement of the apparatus will be seen from Fig. 60. A vertical wire mounted in front of the condenser is projected by means of the lens L via the galvanometer mirror on to a distant boldly marked scale. It is then

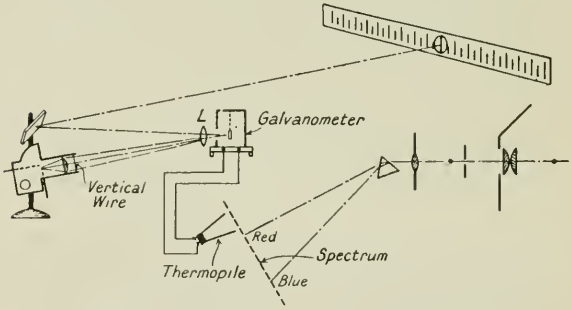


Fig. 60.—Experiment for Demonstrating Infra-red Radiation (diagrammatic).

arranged that the spectrum can be made to pass over the "mouth" of the thermopile, commencing with the visible green (say) and by passing on to the red and finally out into the invisible infra-red, the deflections on the galvanometer scale can be recorded. For an elementary lecture experiment such as this is, the lenses and carbon disulphide prism used for forming the spectrum may be of glass, as these will transmit radiations freely up to 2μ. The thermopile may be of the Nobili type, and a D'Arsonval moving-coil galvanometer will

be found quite suitable for this experiment—it is desirable to have the resistance of the galvanometer approximately similar to that of the thermopile.

APPARATUS:—Optical bench and projection lantern—3 saddles.
O.B. Fittings:—Slit (C, Fig. 2).
8 in. focus projection lens (E, Fig. 2).
Small table (D, Fig. 2).
60° carbon disulphide prism.
Thermopile.
Galvanometer—scale and lamp for this.
ROOM:—Dark.

(*j*) Dispersion.

In dealing with this subject two outstanding experiments are of interest: one is to show deviation without dispersion and the other dispersion without deviation.

In the former case, an illuminated slit is projected on the screen and one prism of an achromatic prism system

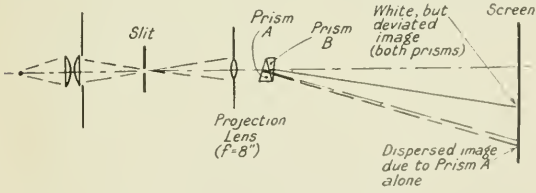


FIG. 61.—ACHROMATIC PRISM EXPERIMENT.

placed in the beam. The spectrum thus formed may then be nullified by placing the second prism of the combination in contact with the first, when it will be noticed that not only is the slit image rendered white but considerable deviation of the beam is produced (Fig. 61). Although the lecturer will probably prefer to buy the

"achromatic prism" complete, the following details of a pair of prisms used by the writer for some time may be of help.

Prism	Angle	n_D	Mean Dispersion, C—F	ν value	Composition
A	29°	1·516	·0081	63·8	Boro-silicate Crown
B	16°	1·576	·0140	41·0	Light flint

In order to demonstrate dispersion without deviation a direct-vision prism should be used, first projecting the white image of the slit directly on the screen and then placing the D.V. prism in the beam immediately behind the projection lens. Such prisms of large aperture are not always easy to obtain and therefore a detailed diagram of such a prism (which can be made up in the laboratory) is given in Fig. 62. Two crown prisms—of the angles shown—are cemented down to a piece of plate glass cut to the required dimensions. A top and two side plates are also cemented on, thus making a central hollow prism into which carbon disulphide is poured through the hole indicated. Plaster of Paris will be found a suitable cement for this purpose; the commercial glue "Seccotine" is also satisfactory for cementing any vessel in which CS_2 is to be held.

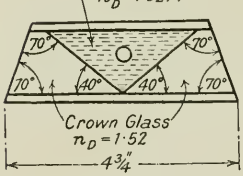


Fig. 62.—Direct-vision Prism for Projection Work.

Apparatus:—Optical bench and projection lantern—3 saddles.
O.B. Fittings:—Slit (C, Fig. 2).
8 in. focus projection lens (E, Fig. 2).
Small table (D, Fig. 2).
Achromatic prism combination.
Direct-vision prism.
Room:—Dark.

(*k*) Chief Spectrum Lines used in Dispersion Measurements.

The chief lines used in the determination of the optical constants of glass, namely the sodium D line(s) and the hydrogen C, F, and G′ lines, may be shown to students by projecting them on the screen in lantern-slide form by the following method. A lantern slide on which there is a coloured transparency of a continuous spectrum can be obtained from Messrs. Newton & Co., 72 Wigmore Street, W.1. Two masks should then be prepared, consisting of fully exposed lantern-slide glasses on which lines ($\frac{1}{32}$ in. or $\frac{1}{16}$ in. wide) have been ruled at the correct position of the D line in one case and the C, F, and G′ lines on the other slide (see Fig. 63). If now these in turn be superimposed on the coloured transparency and put in the lantern, we shall have the sodium and hydrogen spectra respectively projected on the screen.

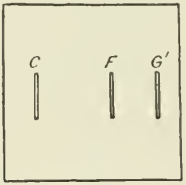


Fig. 63.—Mask for Demonstrating Line Spectra (Hydrogen).

IX

POLARIZATION EXPERIMENTS

(*a*) Polarization by Reflection.

A circular aperture A (Fig. 64) is projected on the screen by the (8 in. focus) lens L by light which has been reflected at R_1, making an angle of 33° with the axis. This reflector, as does R_2, consists of a piece of thin plate glass 8 in. × 4 in. × $\frac{1}{16}$ in., the lower surface of which is

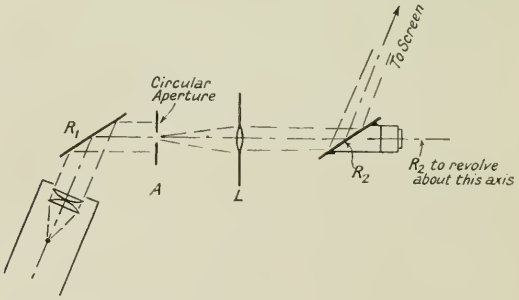


Fig. 64.—Polarization by Reflection. Plan View of Apparatus.

coated with black French polish (or some black varnish). R_2 is adjusted parallel to the first reflector and is arranged so that it can rotate about an axis R_1R_2. When the two plates are parallel—as in the figure—the image of the aperture will appear on the screen; if now R_2 is made to rotate slowly, the image will pass up the side of the wall

and on to the ceiling, gradually becoming fainter during this process until on reaching the position when the two reflectors are at right angles, it will become totally extinguished.

Apparatus:—Optical bench and projection lantern—4 saddles.
O.B. Fittings:—Aperture plate (A, Fig. 2).
8 in. focus projection lens (E, Fig. 2).
Clip (H, Fig. 2).
Rotating holder (B, Fig. 2) with wooden plug to carry reflector.
Two pieces of glass, 8 in. × 4 in., blackened at the back.
Room:—Dark.

(*b*) Tourmaline Experiment.

The following experiment is a fundamental one in polarization. Fig. 65 shows two pieces of tourmaline (cut parallel to axis and about 1 mm. thick) mounted in a framework on adjacent pieces of glass, so that it is possible to rotate one over the other by means of the milled head H. If the tourmalines are projected on the screen in the usual way (see Fig. 66) and first placed so

Fig. 65.—Tourmalines in Special Mount.

Fig. 66.—Tourmaline Experiment.

that their long axes are parallel, a quantity of the incident light will be transmitted; if one is then rotated, the

illumination in the centre will gradually decrease, the light becoming finally extinguished when the tourmalines are at right angles.

Apparatus:—Optical bench and projection lantern—2 saddles.
4 in. focus projection lens (E, Fig. 2).
Tourmaline in special mount.
Holder (B, Fig. 2) for above.
Room:—Dark.

(*c*) Polarization by Pile of Plates.

A pile of ten thin sheets of white plate glass (6 in. square) mounted in a framework so that they can rotate about a horizontal axis (see Fig. 67) is necessary for this experiment.

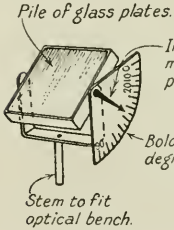


Fig. 67.—Pile of Plates mounted for use with Optical Bench.

The circular aperture A (Fig. 68) is illuminated by a parallel beam from the projection lantern, and the 12 in. focus lens L forms an image of the aperture on the screen. At the principal focus F of this lens is placed a Nicol prism—this need only be of small aperture ($\frac{3}{8}$ in. across the small diagonal) as the beam is constricted at this point—and following this the pile of plates. The Nicol should be rotated so that the short diagonal (as viewed end-on) is vertical, and then the pile of plates gradually swung from the vertical position until the reflected image of the aperture seen on the ceiling of the room appears extinguished—the reading of the arm on the scale should then read 57° ($n = \tan i$ where i is the polarizing angle).

It will be noticed, however, that there is a fully illuminated image on the screen, transmitted *through* the plates, and as the vibration direction of the emergent beam from the Nicol can be taken as being parallel to the short diagonal of the prism, it follows that the vibration direction of the light after passage through the plates

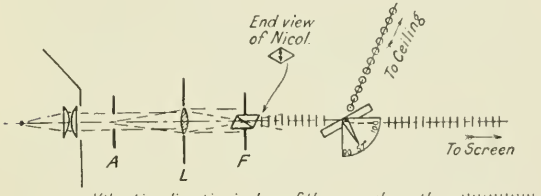


Fig. 68.—Polarization by Pile of Plates.

is perpendicular to the plane of the plates, and parallel to the plates for the reflected beam. This can be further made clear, by rotating the Nicol prism through 90°, when it will be seen that the image on the screen becomes extinguished and that on the ceiling becomes illuminated.

Apparatus:—Optical bench and projection lantern—4 saddles.
O.B. Fittings:—Aperture plate (A, Fig. 2).
8 in. focus projection lens (E, Fig. 2).
Nicol prism (rotatable) in stem fitting (Fig. 70).
Pile of plates mounted on stem fitting.
Room:—Dark.

(*d*) Projection of Objects in Polarized Light.

In order to do this satisfactorily the apparatus depicted in Fig. 69 will be required. The source of light and

the condenser are adjusted to give a parallel beam, in the path of which is placed a polarizer P. This latter may

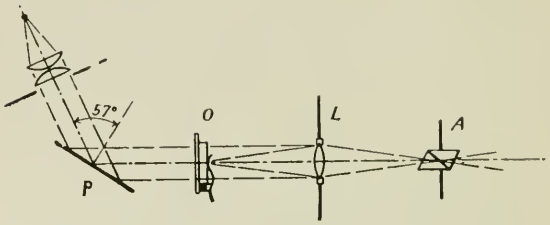


Fig. 69.—Polarization Projection Apparatus for Experiments in "Paralell" Light.

take the form of a piece of sheet glass blackened at the back and set at the appropriate angle to the axis (see the

Fig. 70.—Nicol Prism in Rotating Mount.
The white line indicates the vibration direction of the Nicol.

Fig. 71.—Glass in Screw Press.

figure); quite satisfactory projection can be obtained with this simple polarizer, but if more complete polarization

of the incident light is required, a Rochow prism with suitable diaphragm (of about $1\frac{1}{2}$ in. aperture), a Fuessner prism, or a large aperture Nicol may be employed —these latter, however, naturally involve greater expense than the former.

At O is placed the rotary holder (B, Fig. 2) for carrying the object, and the 8 in. focus lens L is arranged to project the image of the circular opening on the screen. At the principal focus of this lens the Nicol prism A of small aperture (Fig. 70) is placed. By rotating the Nicol about a horizontal axis, the effect of "crossed" and "parallel" Nicols may be shown. The object may then be inserted in the holder O and its appearance shown to the class as a whole. The kinds of object that can be projected to demonstrate the effect of polarized light on them, are both numerous and varied, therefore a few of the better ones only are suggested here:—

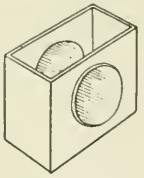


Fig. 72.—Metal Tank with Glass Side-plates.

(1) A small block of well annealed glass may be compared with a piece of "chilled" glass.

(2) A cube of glass held in a screw press and slowly tightened (Fig. 71); or a similar cube supported in an empty tank with glass sides (Fig. 72) is projected on the screen, and hot water then poured into the tank.

(3) A strained lens in its cell, such as a telescope objective, or a spectacle lens in its frame.

(4) Piece of selenite of varying thickness.

Apparatus:—Optical bench and projection lantern—4 saddles.
O.B. Fittings:—Clip (H, Fig. 2).
Rotary holder (B, Fig. 2).
8 in. focus projection lens (E, Fig. 2).
Nicol prism in mount (Fig. 70).
Piece of sheet glass, 8 in.×4 in., blackened at back.
Various objects as suggested.
Room:—Dark.

(*e*) Double Refraction.

The experiment by Bartholinus in 1669, when he discovered the bi-refracting power of a crystal of Iceland spar, may be reproduced by projection in the following way:—The image of a small hole is formed on the screen by the 8 in. focus projection lens as in Fig. 73. A crystal of calcite (1 in. to $1\frac{1}{2}$ in. in thickness) is then held

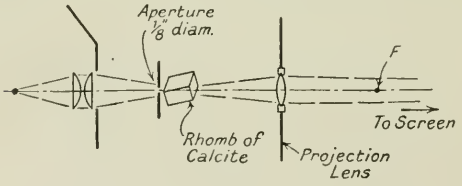


Fig. 73.—Rhomb Experiment illustrating Double Refraction.

immediately against the small hole, when the doubling of the image will at once become evident.

The crystal should be held in a suitable mount (see description below) so that it may be rotated about a horizontal axis; the manner in which the "extraordinary image" rotates round the "ordinary image" can then be shown.

The aperture should be removed temporarily and the

front face of the crystal projected on the screen; a spot of Indian ink is then put on this face, and the fact demonstrated that a line passing through the two images seen is parallel to a line joining the two solid obtuse angles of the crystal (see Fig. 74).

Further, if the ink-spot is removed, and the small hole again placed in front of the crystal, by inserting the Nicol prism at the focus F of the projection lens and by rotating it, it can be shown that the ordinary and

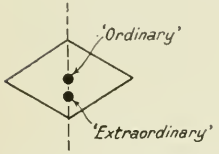


FIG. 74.—VIEW OF RHOMB AS PROJECTED ON SCREEN, SHOWING ORDINARY AND EXTRAORDINARY BEAMS.

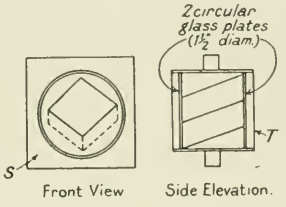


FIG. 75.—MOUNT FOR CALCITE RHOMB.

extraordinary beams are both plane-polarized beams but with their vibration direction at right angles to one another.

A convenient method of mounting the spar crystal for these experiments is to cement two circular glass end-plates with Canada balsam on to the crystal as indicated in the elevation view of Fig. 75. These plates in turn fit inside a metal tube T to which is soldered the square plate S, the whole being held in the rotary mount (B, Fig. 2).

APPARATUS:—Optical bench and projection lantern—4 saddles.
O.B. Fittings:—Aperture plate (A, Fig. 2).
Rotary mount (B, Fig. 2).
Nicol prism fitting (Fig. 70).
Crystal of Iceland spar mounted as in Fig. 75.
Various cleavage rhombs of spar of poor quality to pass round class for viewing a page of print.
ROOM:—Dark.

(*f*) Double Refraction by Quartz.

For this experiment it is desirable to have a natural crystal of quartz (say 3 in. long by $1\frac{1}{2}$ in. across opposite faces) with two of the faces parallel to the axis ground and polished (see figure), thus making a 60° prism, but otherwise not altering the natural shape of the crystal. If the apparatus is now arranged as in Fig. 76 two spectra

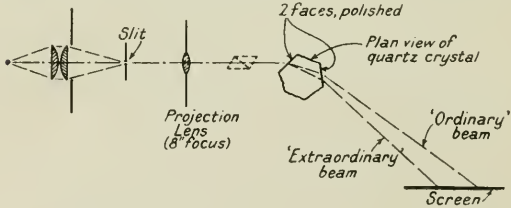


FIG. 76.—ILLUSTRATING DOUBLE REFRACTION BY QUARTZ.

will be seen projected on the screen, one due to the ordinary beam and one the extraordinary; or if monochromatic light be used (i.e. by employing a filter) two images of the slit will be apparent.

If the crystal be replaced by a quartz prism whose refracting edge is at right angles to the optic axis, the single spectrum which now appears has the same deviation

as the least deviated spectrum in the preceding experiment (i.e. the "ordinary" beam).

Further, by using the crystal as in the first experiment and by placing the rotatable Nicol in the path of the incident light as shown dotted in the figure, either spectrum may be extinguished for a 90° turn of the Nicol, showing that the ordinary and extraordinary beams are polarized at right angles to one another. Moreover, by knowing the vibration direction of the light emerging from the Nicol it is easily shown that the vibration in the ordinary beam takes place *across* the axis of the crystal, whilst that of the extraordinary beam takes place *along* the axis.

APPARATUS:—Optical bench and projection lantern—4 saddles.
O.B. Fittings:—Slit (C, Fig. 2).
8 in. focus projection lens (E, Fig. 2).
Small table (D, Fig. 2).
Nicol prism fitting (Fig. 68).
Natural quartz crystal with two faces polished (as described).
ROOM:—Dark.

(*g*) Rotary Polarization.

The apparatus should be set up as in Fig. 77, the circular aperture of the object-holder O being projected on to the screen. A plate of quartz (2 mm. thick, cut perpendicular to the axis) will be required. It is preferable to have two such plates, one from a right-handed crystal and one from a left-handed; moreover, if the natural crystals from which the plates have been cut can be exhibited, it is helpful to the student for realizing that the plates are cut *perpendicular* to the axis, as the

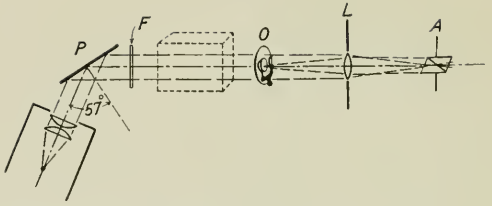


Fig. 77.—Apparatus for Experiments on "Rotary" Polarization.

optic axis in quartz runs parallel to the long external faces (see Fig. 78).

Fig. 78.—Plate of Quartz cut perpendicular to the Axis of the Crystal.

A colour filter F (Fig. 77) transmitting (say) red light *only* is interposed in the beam and the analyser A "crossed" so as to extinguish the light on the screen. One of the quartz plates is then placed in the holder O, when it will be noticed that light appears on the screen, and the Nicol A must now be rotated through a certain angle to produce extinction again. If green light only is then used it will be found necessary to rotate the analyser further, and for blue a still greater rotation will be required to produce extinction.

Apparatus:—Optical bench and projection lantern—5 saddles.
O.B. Fittings:—2 clips (H, Fig. 2).
Object holder (B, Fig. 2).
8 in. focus projection lens (E, Fig. 2).
Nicol prism fitting (Fig. 70).
Polarizer (blackened glass).
Piece of right- and left-handed quartz.
Light filters.

Room:—Dark.

(*h*) **Spectro-polariscope.**

Although reliable colour filters having selective transmissions can now be obtained—(the foregoing experiment will not be a success if inefficient filters are used)—an excellent modification of this experiment is provided by using pure colours produced by a spectrum. Fig. 79

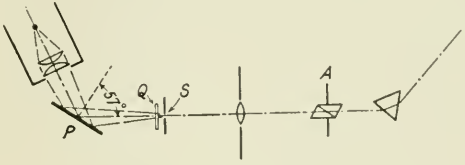


Fig. 79.—Spectropolariscope.

shows a form of combined polariscope and spectroscope arranged for lecture projection work. If one of the quartz plates Q be placed in front of the slit S, by a slow rotation of the analyser A, a dark band will be seen to move right through the spectrum, illustrating the increase in rotation of the plane of polarization for different wave-lengths.

Apparatus:—Optical bench and projection lantern—6 saddles.
O.B. Fittings:—Clip (H, Fig. 2).
Slit (C, Fig. 2).
8 in. focus projection lens (F, Fig. 2).
Nicol prism fitting (Fig. 70).
Small table (D, Fig. 2).
Sheet glass polarizer.
{D.V. prism (Fig. 62), or
{60° carbon disulphide prism.

Room:—Dark.

(*i*) Hand of the Crystal.

With the apparatus as in Fig. 77 but without the filter F (i.e. using white light) and with one of the quartz plates in the holder O, the analyser should be rotated in a direction such that the colours appear on the screen in the following order: red, yellow, green, blue. If one imagines one's back towards the projection screen and looking towards the apparatus, a rotation of the analyser in a clockwise direction to produce the above order of the colours would indicate a *right*-handed crystal; and an anti-clockwise rotation to produce the same order of the colours, a *left*-handed one.

Apparatus:—As in experiment (*g*) of this section.
Room:—Dark.

(*j*) Rotary Power of Solutions.

Certain solutions, such as those of the sugars, turpentine, etc., will also rotate the plane of polarization. This may be demonstrated by first projecting the image of the circular aperture of the object-holder O (Fig. 77), using monochromatic light and extinguishing this image with the analyser A, and then inserting between the monochromatic filter F and the holder O a glass tank (6 in. in length) shown dotted in the figure containing either turpentine or (say a 40 per cent. by weight) solution of cane sugar. It will be seen that light again appears on the screen and the analyser will have to be rotated through a reasonably large angle in order to restore extinction. Turpentine will produce a left-handed rotation, and the cane-sugar solution a right-handed.

APPARATUS:—As for experiment (*g*) in this section, with the addition of a glass cell and solutions.
ROOM:—Dark.

(*k*) Bi-quartz.

Using the apparatus in Fig. 77, but without the filter F, the purpose of a *bi-quartz* may be illustrated. By mounting such a specimen [1] (either natural or artificial) in the holder O and projecting the dividing edge of the bi-quartz on the screen, the analyser should be rotated until both halves are of the same tint. If, then, the tank containing one of the above liquids be placed between O and L in the figure, the match in colour will be destroyed and the analyser must be rotated to again restore the equality of the two halves of the field.

APPARATUS:—As for experiment (*g*) in this section, with the addition of a bi-quartz.
ROOM:—Dark.

(*l*) "Convergent" Light.

The examination of crystals in "convergent" polarized light, for such purposes as (1) the differentiation of uni-axial and bi-axial types, (2) the determination of the direction of the optic axis with respect to the plane of section, (3) the determination of the "fast" and "slow" vibration directions with respect to the plane containing the axes, and so on, can be carried out by projection as depicted in Fig. 80.

In the path of the polarized beam at A is placed a positive lens of 2 in. focus and a similar lens at the point B, the crystal itself being mounted at the apex of the convergent cone. A circular aperture with a pin soldered

[1] Obtainable from Messrs. Griffin.

to it placed at any convenient position beyond B is projected on the screen by the lens L, and as before the analyser placed at the principal focus of this lens.

The familiar "ring-and-brush" figure characteristic of

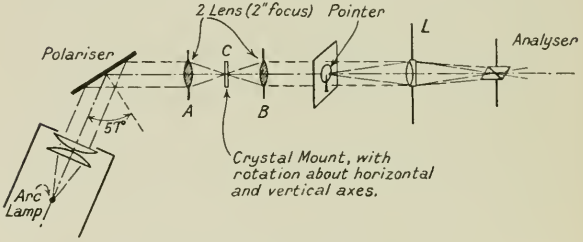


Fig. 80.—Polarization Experiments in Convergent Field.

a uni-axial crystal, and the two "eyes" produced by a bi-axial crystal, may thus be projected on the screen.

Suitable specimens are given below:—

Uni-axial	Bi-axial
Iceland Spar	Aragonite
Beryl	Mica
Sapphire	Biotite
Nitre (soda)	Sugar

Apparatus:—Optical bench and projection lantern—6 saddles.
O.B. Fittings:—3 clips (H, Fig. 2).
8 in. focus projection lens (E, Fig. 2).
Nicol prism (Fig. 70).
Plate with index arm.
Various specimens of uni- and bi-axial crystals.

Room:—Dark.

X

INTERFERENCE AND DIFFRACTION

(*a*) Ripples.

A demonstration of wave motion and wave interference by the projection of mercury ripples is helpful to the student. Unfortunately the apparatus for showing this is not simple and takes some time to set up; nevertheless

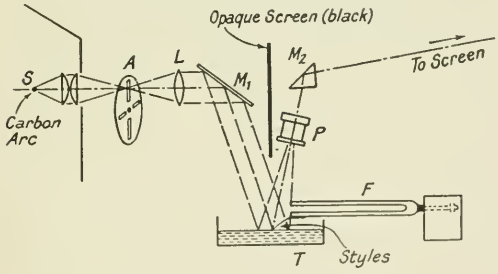


Fig. 81.—Projection of Mercury Ripples.

it should be shown when possible, and therefore the method is described here.

Light from a strong source of light S (Fig. 81) is focussed by means of the usual condenser to a point A. A 4 in. diam. lens L renders the beam parallel, and a silvered mirror M_1 reflects it down on to the surface of some mercury held in a trough T. The projection lens P

(12 in. focus) mounted immediately above the mercury surface produces an image of this on the screen via the right-angled prism M_2. A tuning fork F (12 in. long and with a frequency of about 80 vibrations per sec.), to one prong of which is attached two fine glass styles, is arranged to project over the mercury surface and the styles just to rest on the surface. A stroboscopic sector (having four slits $\frac{1}{4}$ in. wide) is made to rotate in the path of the beam at A; this is driven at a speed of from 200 to 300 revolutions per minute by a small motor, in whose circuit is a variable resistance for adjustment. On gently striking the fork circular ripples of equal amplitude will be generated by each style, these being observed on the screen; on those parts of the mercury surface where the two sets of ripples overlap, the effect of "interference" and "reinforcement" will be seen.

APPARATUS:—As described (special).
ROOM:—Dark.

(*b*) Young's Experiment.

This experiment, whilst almost impossible to project on a distant screen in the lecture theatre and thus to

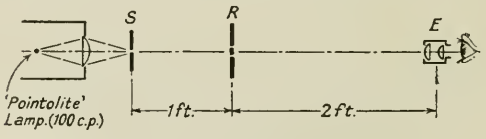


FIG. 82.—YOUNG'S EXPERIMENT.

show a class as a whole, is of such fundamental and historical importance that no apology need be made for

setting up the apparatus and allowing each student to view the fringes in turn.

A slit S (Fig. 82) is illuminated by a "pointolite" lamp and condenser and at position R is placed a double slit made by cutting two parallel lines $\frac{1}{2}$ mm. apart on an exposed photographic plate. An eyepiece at E is arranged to view the interference bands produced. The double slit must be adjusted to be parallel to the single slit, and therefore it is desirable to hold the former in the rotating mount (Fig. 2, B).

Apparatus:—Optical bench—3 saddles.
O.B. Fittings:—Slit (C, Fig. 2).
Rotary mount (B, Fig. 2).
Eyepiece mounted on stem fitting.
" Pointolite" lamp.
Room:—Dark.

(c) Lloyd's Fringes.

The interference fringes obtained by Lloyd's single-mirror method are of a brighter nature than those produced by the double slit method and can with little

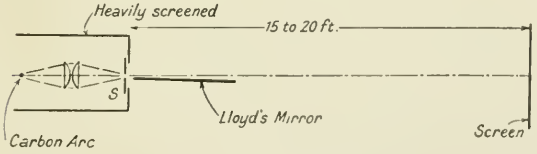


Fig. 83.—Projection of Lloyd's Fringes.

difficulty be shown on the lecture-room screen. Further, the experiment is quite easy to set up, the fringes being nearly always found at the first attempt. The slit S (Fig. 83) is strongly illuminated—using an arc lamp—

and the Lloyd's mirror placed close to and parallel with the slit; it should be adjusted so that an observer looking towards the slit with the unaided eye can see the direct image and the reflected image only just separated; excellent fringes will then be seen on the screen some 15 to 20 ft. away. The mirror may be a piece of reasonably flat plate glass (about 12 in. long × 2 in. wide), the back surface of which has been blackened.

APPARATUS:—Optical bench and projection lantern—2 saddles.
O.B. Fittings:—Slit (C, Fig. 2).
Small table (D, Fig. 2).
Plate-glass mirror mounted on above table with soft wax.
ROOM:—Completely dark.

(*d*) Bi-prism Fringes.

By employing a Fresnel bi-prism, the interference bands are also of sufficient brightness to be projected on to a distant screen. Fig. 84 will make the experiment

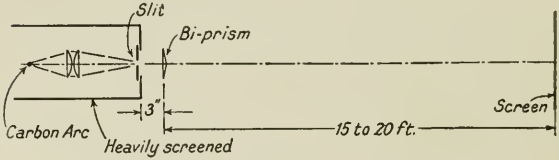


FIG. 84.—PROJECTION OF INTERFERENCE BANDS WITH BI-PRISM.

clear. Care must be taken to get the edge of the bi-prism parallel to the direction of the slit; the use of the rotary mount for holding the prism enables this to be done conveniently.

APPARATUS:—Optical bench and projection lantern (arc lamp)—2 saddles.
O.B. Fittings:—Slit (C, Fig. 2).
Rotary mount (B, Fig. 2).
Fresnel bi-prism.
ROOM:—Completely dark.

(*e*) Newton's Rings.

The interference rings seen when a long-focus lens is rested on a flat glass plate, can be projected on the screen

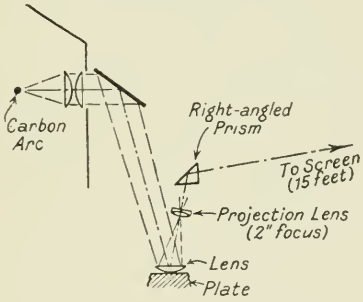


FIG. 85.—PROJECTION OF NEWTON'S RINGS.

by the method shown in Fig. 85, which will be found self-explanatory. The apparatus is similar to that used for the projection of opaque objects (given in exp. (*f*), Chapter VII), except that the object in this case is the lens and plate (see figure). The lens surface in contact with the plate should have a long radius, something of the order of 1 metre, whilst the plate should have its back surface blackened to stop reflections therefrom. It is essential to have a strong source of light (e.g. the 10-ampere arc), also the lens and plate should be well

cleaned before being placed in contact. These two points have considerable bearing on the success of the experiment.

(*f*) Testing Flatness of Optical Surfaces.

Using the same apparatus as in the foregoing experiment, a demonstration of the appearances seen when testing a flat surface of poor quality against an "optical proof plane," can be given by placing two such surfaces in contact and then putting them in the position previously occupied by the lens and plate. The effect due to interference produced by a thin film of air between two glass surfaces can thus be shown. [It will be found advantageous to use the 13 in. focus lens for projection instead of the 2 in. focus lens as used in the last experiment.]

(*g*) Thin Films on Water.

If a bowl (whose inner surface is painted black) be filled with water and placed as before in the position of the lens and plate, and then a drop of liquid celluloid (celluloid dissolved in amyl acetate) be allowed to fall on the surface, the coloured fringes thus produced will be projected on the screen and made visible to the class.

Apparatus for the three foregoing experiments:—
Projection lantern with arc lamp as source.
Silvered mirror, 4 in. square.
2 in. projection lens.
13 in. focus projection lens.
Right-angled prism.
Flat glass plate.
+ 1 diopter spectacle lens.
Bowl of water.
Room:—Dark.

(*h*) **Soap Bubble.**

An effective experiment to show the interference of light by thin films is to show the colours produced by a soap bubble. To do this, a few minor points should be given attention in order that the class shall see the colours well. The room must be in complete darkness, and a diffused extended source of light is required. This can be provided by housing a *bright* lamp inside a box in one end of which a piece of ground glass is fitted (Fig. 86).

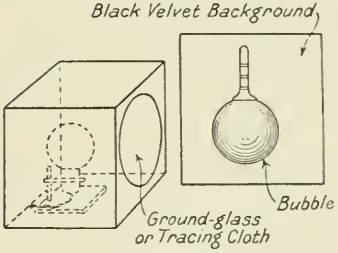


Fig. 86.—Interference Colours of a Soap Film.

The bubble when blown should be held near the ground glass but should have as dark a background as possible. If it is possible to use a strong monochromatic source of light inside the box such as a mercury vapour lamp, the alternate light and dark concentric rings can be seen extending from the equator down to the bottom of the bubble, gradually becoming closer as the film becomes thicker. The soap solution may be made with any good-quality soap—medicated soft soap with water and a little glycerine added will be found to give good results.

APPARATUS:—Box with ground-glass side.
"Pointolite" lamp.
Pipe or straw for blowing the bubbles.
Soap solution in crystallizing dish.
ROOM:—Dark.

(*i*) Diffraction Experiments (the Grating).

Diffraction phenomena, like interference effects, are difficult to project on a distant screen, so that the whole class may see them at once. There is, however, one experiment in this connection which projects satisfactorily, namely that illustrating the diffraction grating. If the apparatus (Fig. 87) be arranged to project an image of a slit on the screen, and then a transmission grating be

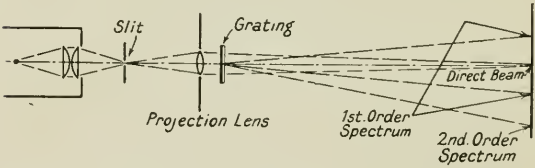


FIG. 87.—DIFFRACTION GRATING EXPERIMENT.

interposed in the beam (as indicated) with its rulings parallel to the direction of the slit, some two or three orders of diffraction spectra on either side of the direct beam will be seen. Gratings of relatively coarse rulings, such as 1,000 or 2,000 lines per inch, give best results for this experiment, as the spectra are not too widely displaced for convenient projection.

If two or more gratings of different rulings (say 250 lines per inch, i.e. a piece of process screen; 2,000 and

6,000 lines per inch) are available, it is of interest to show the increased angular displacement of the spectra with gratings of an increasing number of rulings per inch.

It is instructive also to cover the upper half of the slit with a monochromatic red screen and the lower half with a monochromatic blue, when the greater displacement of the diffracted beams for the longer wave-length will be clearly evident.

APPARATUS:—Optical bench and projection lantern—3 saddles.
O.B. Fittings:—Slit (C, Fig. 2).
12 in. focus projection lens (F, Fig. 2).
Clip (H, Fig. 2).
Several gratings (of rulings suggested).
ROOM:—Dark.

(*j*) Other Diffraction Experiments.

If a point source (e.g. an illuminated aperture 1 mm. diam. in a metal plate) be erected on the lecture table facing the class, and each student be given a small piece of "Jap" silk through which he may observe the source, the two sets of spectra at right angles will be plainly revealed. Alternatively the slit in Fig. 87 can be replaced by the small hole and the grating by a piece of wire gauze, when a similar effect will be produced on the screen.

The more familiar diffraction effects seen with such objects as (1) straight edge, (2) needle, (3) tapering narrow slit, (4) steel ball, (5) circular plate (to show Poisson's disc) are not altogether successful when projected on the distant screen owing to the low luminosity incurred. This is possible, however, at a distance of 6 ft. from the source and consequently some eight or twelve students

near the screen can see the appearance at one time. Nevertheless, the effects are best observed by setting up the apparatus on the optical bench, as in the case for interference experiments (see Fig. 82), and allowing individual inspection through the eyepiece E. For objects (4) and (5), however, the source S will have to be a small round hole about $\frac{1}{2}$ mm. in diameter.

XI

THE LECTURE THEATRE AND ITS EQUIPMENT

The proper equipment and fittings of a lecture-room are essential points in the success of lecture work and experiments, and whilst most theatres have to serve for all kinds of subjects, the following lay-out is suggested for a lecture theatre in which Optics is to be taught. Whilst it may not differ greatly from the average physics theatre, the following account may be found useful.

The general arrangement of the room in plan view will be gathered from Fig. 88. It is essential in Optics to be able to make the theatre at times completely dark, and therefore provision must be made to cover all windows with opaque blinds. It is convenient to have one switch on or near the lecture table with which all the overhead artificial lighting can be extinguished at will. It will be found useful to have one screen for the projection of lantern slides, whilst a second one slightly inclined to the side wall is suitable for projection with the lecture experiments—it is helpful to have this hinged at A so that it can be swung out to vary the angle with the axis of the bench. The whitened ceiling (if flat) immediately above the lecture table can be of service in some experiments.

The blackboard may with advantage consist of the

double raising and lowering type, preferably of ground glass and with one "board" marked in squares. Coloured chalks are conducive to good optical diagrams, and the frequent occurrence of circles employed in such drawings justifies the use of the simple form of blackboard compass

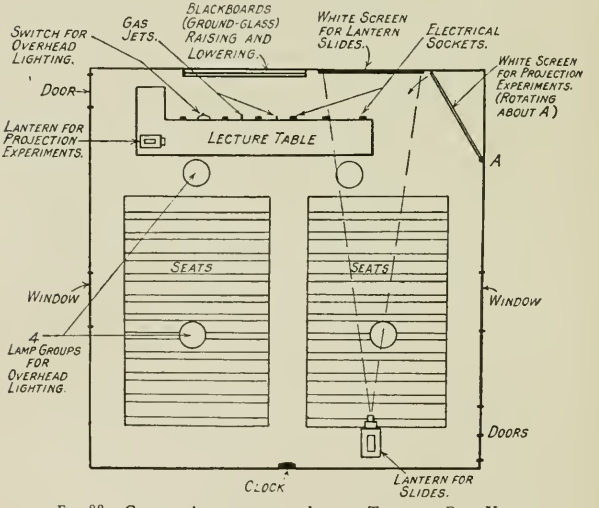


FIG. 88.—GENERAL ARRANGEMENT OF LECTURE THEATRE. PLAN VIEW.

suggested in Fig. 89. The grooved metal portion is held against the board and a turn of the string is taken round the chalk at any desired radius, and the arc described when extending the string to its fullest amount.

The lecture table should be from 12 to 15 ft. long and 2 ft. 6 in. wide, preferably with an extension at right

angles at one end, as shown in the diagram; this is of convenience in many experiments, especially those involv-

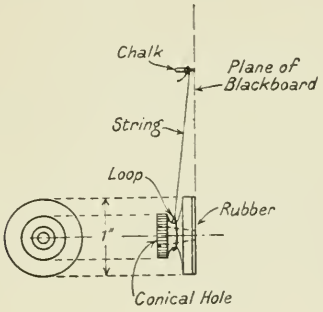


Fig. 89.—Blackboard Compass.

ing projection with a 60° prism, which is frequent in Optics.

The table should be well furnished with points from which electrical supply can be taken off—six plug-sockets are not too many—also one or more gas-jets are necessary.

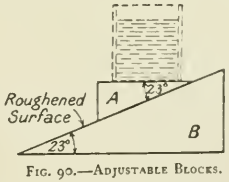


Fig. 90.—Adjustable Blocks.

The resistances for the projection lamps can be screwed to the side of the table. Space under the bench can be usefully occupied for storing a few retort stands and

wooden blocks; these latter are distinctly valuable and a range such as the following sizes will be found of use: 10 in., 7 in., 5 in., 3 in. cubes; 6 in. square × 3 in. deep; 6 in. square × 2 in. deep; 6 in. square × 1 in. deep; two of each will make a supply to draw on. A further type of block which is adjustable and to be recommended is shown in Fig. 90. It consists of two triangular blocks (3 in. wide), each with one acute angle of approx. 23° laid one on the other as indicated in the figure; the alteration in height of the supported object is effected by sliding A along the inclined surface of B.

Odd pieces of white card and black paper and some sticks of soft wax help to complete the equipment.

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